WHARVES AND PIERS

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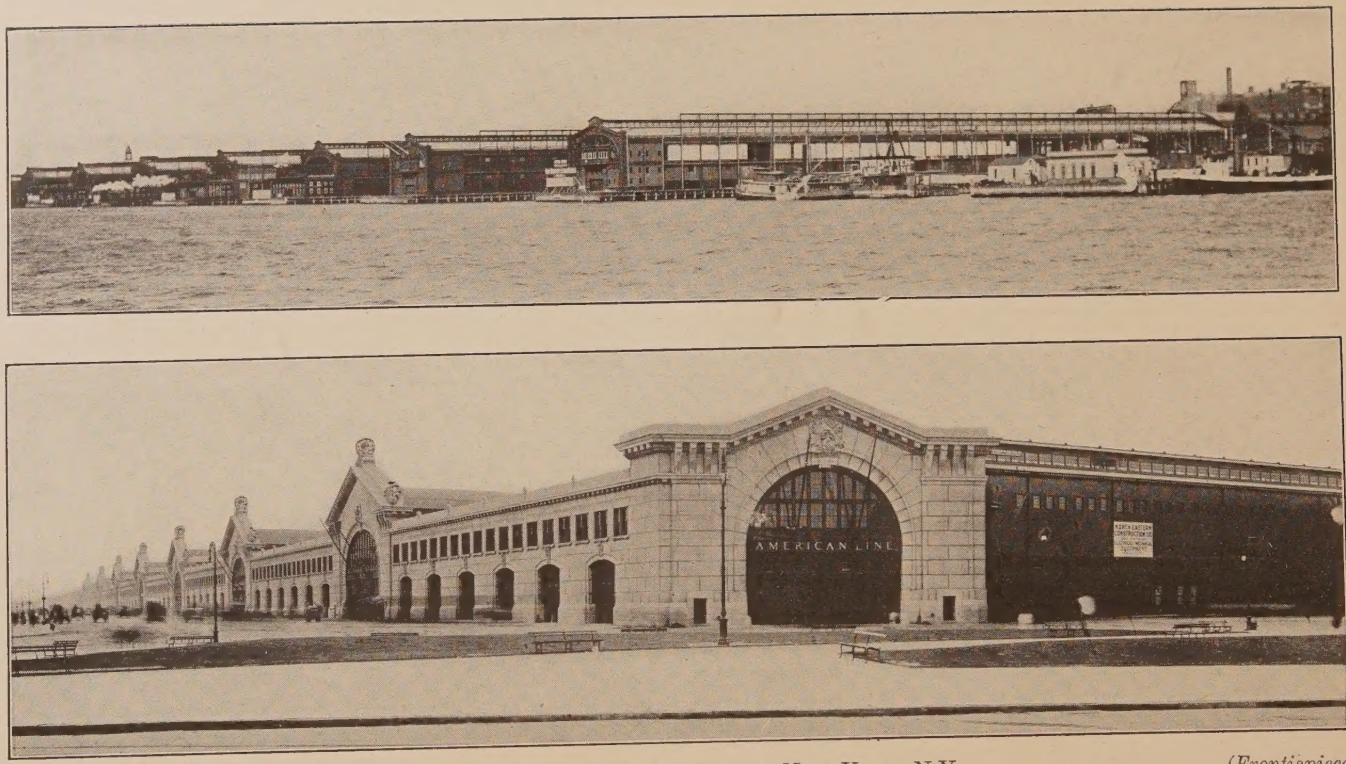

Steamship Piers, Chelsea Section, New York, N.Y. (*Frontispiece*)

WHARVES AND PIERS

THEIR DESIGN, CONSTRUCTION, AND EQUIPMENT

BY

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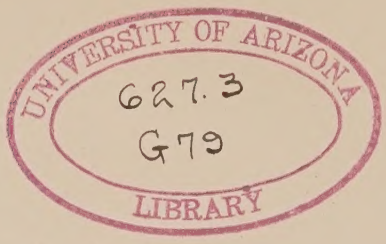

PREFACE

This book has been written in response to an editorial in one of the engineering journals calling attention to the lack of American books on the subject of Wharves and Piers. In its preparation the author has therefore endeavored to present a treatise on modern American practice in the design and construction of wharves, piers, pier-sheds and their equipment, including machinery for handling miscellaneous package freight.

The subject of pile driving has not been gone into deeply as it has been treated at length in Jacoby and Davis' recent work on "Foundations of Bridges and Buildings."

It is the writer's opinion that there is a tendency at the present time to slight the advantages of timber construction for wharves and to overestimate those of reinforced concrete. As the principles and methods requisite for durability in wooden wharf construction have, as far as the writer knows, not been set forth in book form they have been given particular attention in this volume.

While most of the descriptions and illustrations of existing structures have necessarily been collected from the technical press, for which no originality is claimed, an attempt has been made to emphasize, in describing such structures, the particular conditions which had to be provided for in the design, the methods used for fulfilling the special requirements and, to some extent, the reasons why particular types and details were adopted. It is believed that such descriptions will aid designers in solving problems which embrace similar conditions.

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For information in regard to European practice in the construction of wharves and piers the reader is referred to "Seehafenbau" by F. W. Schulze: Berlin, Ernst & Sohn 1913, and for further information in regard to the New York practice in freight handling to the Report on the "Mechanical Equipment of New York Harbor" by B. F. Cresson, Jr., and Chas. W. Staniford and to other reports published by the Department of Docks. In Fowler's "Subaqueous Foundations" may be found examples of the wooden piers of the Pacific Coast and in the latest edition of Merriman's "American Civil Engineers' Pocket Book" there is much valuable information in condensed form.

Acknowledgments are due to Mr. Charles W. Staniford, Chief Engineer of the Department of Docks, New York, N. Y., and to the other officials of that department for photographs, drawings and information; to Mr. S. W. Hoag, Jr., for permission to reprint portions of his paper on New York docks, published in the proceedings of The Municipal Engineers of New York, to *Engineering News*, *Engineering Record*, *Engineering Contracting* and *International Marine Engineering*, also to the General Electric Co., Lidgerwood Mfg. Co., Brown Portable Elevator Co., J. Edward Ogden Co., American Engineering Co. and others for illustrations.

C. G.

New York,
January, 1917

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WHARVES AND PIERS

CHAPTER I

INTRODUCTION

Definitions

The names applied to various kinds of wharves and their parts are loosely used and vary greatly in different localities in this country.

A wharf is a structure at which vessels may land and load their cargoes and passengers. It may be either marginal or projecting, but in most localities the name is applied only to marginal structures, thus distinguishing them from piers.

A pier is a wharf projecting from the shore.

A quay is a marginal wharf. The name is common in Europe, but is used scarcely at all in this country.

A dock is an artificial basin for the use of vessels. Wet docks are those in which the vessels remain afloat for loading and unloading. They are the prevailing type in Europe, where many of the docks are excavated from the land on shores of narrow rivers, and where the range of tide is very great. They are usually provided with gates by means of which the water is maintained at a constant elevation, and their inconvenience, in that vessels can enter and leave them only at high water, is obvious. Dry docks are those from which the water outside is excluded by means of gates and from which the water inside may be removed for the purpose of repairing the underwater portions of vessels. They sometimes are also used for the construc-

tion of ships. The word "dock" is improperly applied to piers in some places in this country, notably in New York, and to marginal wharves in other localities. On the Great Lakes and adjacent waters the word usually means a retaining structure only.

A slip is the space between two adjacent piers, but in some places such spaces are called docks.

A bulkhead wall is a name given in New York City to a retaining wall for a marginal wharf, and the use of this name has spread to other ports.

A dock wall or quay wall is a marginal wall on a wharf or pier.

Requirements of a Wharf

The requirements of a wharf are:

1. Sufficient depth of water for the vessels which are to use it. This is usually obtained by dredging where the natural depth is not sufficient. In some places where the range of tide is very great, small vessels rest on the bottom at low tide or on shelves constructed alongside the wharf for the purpose.

2. Resistance to horizontal forces such as the impact of vessels, currents, floating ice, wind and waves, and, in the case of retaining walls, to the thrust of the earth or other filling.

3. Resistance to vertical forces, the weight of the structure, and of the live loads which it supports.

4. Resistance to decay, abrasion, and the teredo, limnoria, and other destructive marine animals, where the latter exist.

5. Elasticity and non-liability to injure vessels lying alongside. This is particularly important in exposed places where there may be a heavy swell or waves.

6. Non-obstruction to the free flow of water, ice, and sewage and non-diminution of the tidal prism.

7. Non-obstruction of narrow water-ways.

8. Economical construction, considering first cost and

total cost during the probable commercial life of the structure.

9. Rapidity of construction.

10. Security against destruction by fire.

11. Ease in making repairs, also in making additions and alterations and removals due to increase in size of vessels and changes in the nature of the freight and the methods of handling it.

12. Compliance in all navigable waters of the United States with the regulations of the Secretary of War.

Types of Walls

Filled-in piers and marginal wharves require a wall of some sort to retain the filling. Retaining walls may be divided into three classes: gravity walls, or those which depend on the weight of the structure for stability, such as are shown in Figs. 10 and 19; walls with relieving platforms, illustrated in Figs. 44 and 57; and sheet-pile walls, held in place by tie-rods and earth-anchors. The main features of all three types may be combined in various ways, as is shown in subsequent chapters.

Types of Piers

There are three types of piers in general use. The pile-platform, the block-and-bridge, and the solid-filled.

The pile-platform type is perhaps the most common. The platform may be of wood, steel, or concrete and may form the deck of the pier itself or may be located at about low-water level supporting a deck on posts, as in Fig. 74 or a filling of cinders or other material retained in place by a wall around the edge of the pier, as in Fig. 73. The piles may be the ordinary timber or concrete variety or may be in the form of metal or concrete columns of a diameter varying from two to ten feet or more.

The block-and-bridge type, as its name implies, consists of blocks usually of timber cribwork, but in some cases of

concrete or stone masonry resting on the bottom with bridges extending from block to block.

The solid-filled type consists of a retaining wall of some kind along the sides and outer end of the pier with the enclosed area filled in with earth or other material, usually that which is dredged from the slips alongside the pier. The retaining structure may be at the outer edge of the pier, as in Fig. 30, or it may be located inside a pile platform, as shown in Fig. 91.

Materials of Construction

Timber, in most places in this country, is at the present time the cheapest material for the construction of wharves, as far as first cost is concerned. It is, however, liable to destruction by decay, marine animals, and fire.

Air, heat and moisture are necessary for the decay of wood. If wood is constantly wet and deprived of air by being submerged in water or wet earth it will not rot. The necessary heat is present during most of the year in nearly all places where wharves and piers exist and decay is much more rapid in tropical climates than in colder regions. Where wood can be protected from waves, rain, snow, and other direct sources of moisture, the moisture from the atmosphere can best be reduced by good circulation of air. A striking example of decay caused by insufficient circulation of air is found in the piers of the North German Lloyd Co., in Hoboken, opposite New York, shown in Fig. 66. When these piers were built they were surrounded by a tight sheathing of six-inch oak plank extending from low water to the decks. A few years after they were built it was found that the caps and rangers were covered with small masses of fungus and were in danger of decaying. A further examination showed the timber to be saturated with moisture and that the relative humidity of the air under the piers approached saturation when that outside was only about 74%. Enough of the sheathing was removed to give a free circulation of air, whereupon the timber

dried out and the decay has not progressed since to any great extent.

The elevation below which timber is safe from rot in fresh water like the Great Lakes, where the variation of the elevation of the water surface is slow and of small extent, is about one foot below high water. In most tidal harbors timber remains constantly wet up to about half tide and it is usually considered that timber construction below these elevations will last indefinitely as far as decay is concerned. Timber below a plane located two feet above mean low water is considered safe from rot in New York, where the mean range of tide is 4.25 feet, and three feet in Philadelphia, where the tidal range is about 6 feet.

In the rear of bulkhead walls in tidal waters which permit the flow of water through them, it has been ascertained that the rise and fall of the tide is retarded and the time of complete submergence is increased and that therefore the elevation at which timber is safe from decay may be assumed at a higher elevation than outside such walls.

Timber is very durable where it can be protected from rain and waves, as in the interior portions of shedded pile piers, or those with impervious decks. The upper portions of piles known to be over eighty years old have been found in perfect condition in piers in New York. Careful records extending over forty years have been kept by the Department of Docks and Ferries in that city and show that in wooden piers, with wooden decks covered with sheds, such as is shown in Fig. 1, the life and cost of various parts are given in Table I. page 6.

The percentage of average annual cost as given in this table is not quite correct, in that the cost of the removal of

TABLE I

Description[1]	Percentage of total original cost[1]	Renewal required[1]	Percentage of average annual cost of renewal[2]
Deck sheathing	12.0	Every 6 yrs.	2.00
Backing log	1.8	Every 8 yrs.	0.23
Fender chocks, including vertical sheathing	4.0	Every 10 yrs.	0.40
Fender piles	4.7	Every 12 yrs.	0.40
Decking	11.3	Every 15 yrs.	0.75
Bracing	7.1	50 % in every 20 years	0.18
Rangers and caps	24.4	50 % in every 20 years	0.61
Piles	34.7	33⅓ % in every 20 yrs. above M. L. W. only	0.58

the decayed timber has not been included; also, in regard to the last item, the piles decay only above half tide and are repaired by replacing the decayed portion by new timber. It must also be remembered that few of the interior piles of a shedded pier decay to any great extent, so that the splicing is limited largely to the piles on the sides and end of the pier, and the weakening of the structure due to the splicing is not very great. The cost of splicing a pile is from $9 to $12, while the cost of a new 70-foot pile in place is in New York about $16.50. The cost of removing an old pile is about $3.50, making the total cost of entire renewal approximately $20.00. Rangers decay first on the upper surface and are repaired by cutting away the decayed portion and replacing it by spiking on a piece of plank. This of course decreases the strength to some extent.

The durability of untreated lumber depends largely on

[1] C. W. Staniford on pier construction in New York Harbor, p. 515, Trans. Am. Soc. C. E., Vol. LXXVII, 1914. [2] E. G. Walker, ditto, p. 523.

the amount of sap wood it contains, as the sap wood rots much more quickly than the heart. The quality of yellow pine lumber has been deteriorating and the price for material

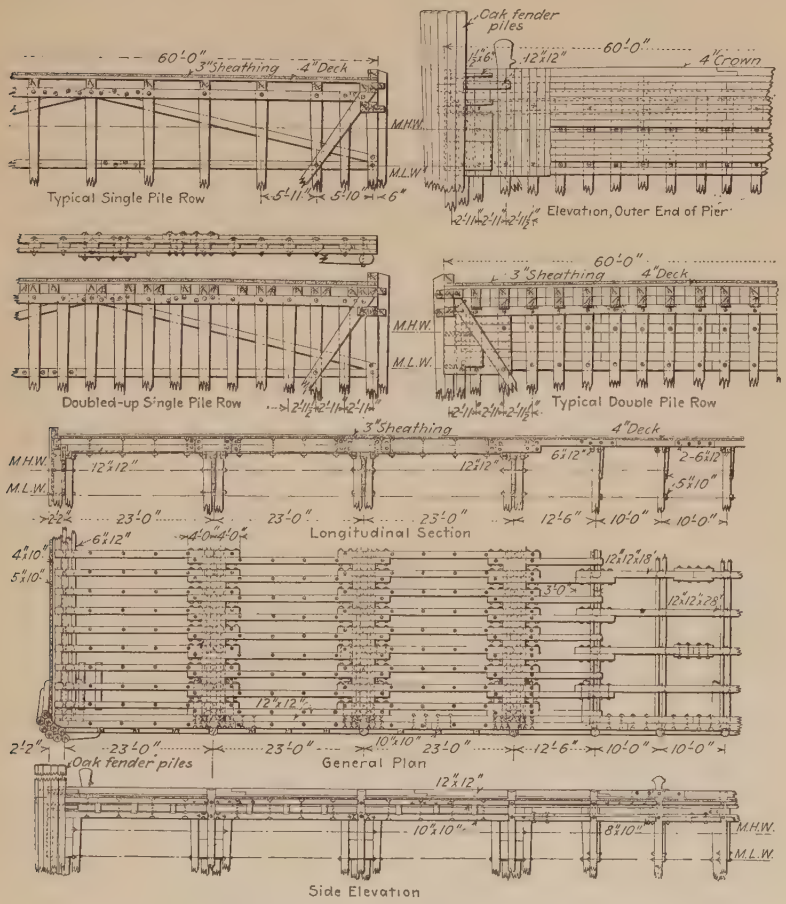

Fig. 1. Wooden Pier, Dept. of Docks, New York, N. Y.

with a restricted amount of sap wood has increased greatly within the last few years. The opening of the Panama Canal has, however, brought Douglas fir into competition with yellow pine, on the Atlantic Coast. This lumber can be obtained entirely free from sap wood and can be

sold profitably at much less than the price recently charged for southern long-leaf yellow pine of poorer quality.

It is very desirable that the energy of moving vessels coming in contact with a wharf be absorbed by the elasticity of the structure rather than by its destruction or by the injury of the vessel. This is evident when we consider that a ship weighing 10,000 tons, moving at a rate of one mile an hour or about $1\frac{1}{2}$ feet a second, has a kinetic energy of about 350 foot tons and for double this velocity the energy is nearly 1500 foot tons and that when such a moving ship comes in contact with a wharf this amount of work must be expended in distorting either the ship or the wharf. It is stated of a very large pier of concrete pile construction that its ability to withstand blows from vessels has been demonstrated and that in every case the plates of the steamers were the sufferers. The owners of ships will shun such a pier if possible and will use in preference one which is elastic and will not injure their vessels. Timber for wharves and piers has advantages over steel, stone, or concrete in the above respect. It also permits of greater rapidity of construction and more easy and rapid alterations, extensions, or removals.

While timber wharves and piers are liable to destruction by fire, it is usually the freight on the pier which starts the fire and causes the greatest portion of the loss. The pier or wharf may, by using only timber of large cross section, be of the slow-burning type of construction and can be so designed that floating, burning materials, such as cotton bales, cannot get under it and that if in any way a fire obtains a hold under the deck it can be reached by the firemen and extinguished. Many instances are known of fires which destroyed the shed and all the freight on a wooden pier but did not burn through the deck or injure the substructure in any way. No method of construction has been adopted, however, which will protect a wooden pier from destruction by burning oil floating on the water. Several fires of this nature caused by the rupture of sub-

merged oil pipe-lines or of oil storage tanks near the water front have occurred, and have usually resulted in the destruction of all wooden piers in the area reached by the oil. Piers of the types shown in Figs. 73, 74 and 75 are not liable to this danger.

Timber piles, unless creosoted, are uneconomical in water infested by marine borers except for temporary structures. Partially creosoted piles last only from fifteen to thirty years, as they are subject to the washing out of the preservative and to the decay of the uncreosoted interior, and completely impregnated piles usually cost nearly as much as those of concrete. In many cities, however, there is enough sewage in the water to drive away the destructive marine animals, and in such places, where the bottom is suitable, wooden piles are cheaper than any other material for the foundations of piers and wharves; at any rate, for structures the commercial life of which will probably not exceed forty years.

Wood Preservatives. — Various forms of coal tar products are used to preserve wood in wharves and piers from destruction by marine borers and from decay. Wood may be treated by the pressure process, in which the material is placed in a closed cylinder and after being treated with steam to remove the sap is then impregnated with the preservative under heavy pressure; by dipping in a tank containing the preservative; and by applying the preservative with brushes. All methods render the timber most unpleasant to handle, as the preservatives are all irritating to the skin and eyes.

Destructive marine animals of one form or another thrive in nearly all salt and brackish water harbors in this country and to the south of it. They are most active in warm waters, but the limnoria is so plentiful at Halifax that concrete piles from 75 to 90 feet in length were used in building steamship piers there, and Puget Sound is noted for the size and abundance of its teredos.

Creosoted piles resist the action of these animals as long

as a sufficient amount of the creosote remains in the wood, but sooner or later enough of the preservative washes out and the borers enter. On the Pacific Coast, where the teredo is very active, creosoted piles are said to have a life of one year for each pound of creosote to a cubic foot of timber. The usual practice is to impregnate the piles to a depth of about 2 inches. This, however, is not a complete protection, as the slightest perforation of the impregnated shell results in the entrance of the teredo and the destruction of the interior portion. The more resinous the wood the more resistant it is to the entrance of the oil of creosote, and cases have been known of the destruction of piles by the entrance of teredos through the knots. The interior portion sometimes rots, though this can be largely prevented by coating the tops of the piles, after they are cut off, with some form of preservative. Complete impregnation of the pile is extremely expensive. Some kinds of timber, Douglas fir in particular, are very resistant to the entrance of creosote into the pores. It is extremely difficult to obtain uniform penetration and in a creosoted pile structure some of the piles are much shorter lived than others. The permanence of the preservative and the durability of the wood after impregnation depends very largely on the nature and quality of the oil, and much attention is at present being given to the study of this point and methods to ensure uniformity of penetration.

In places where marine borers do not exist and where the portion of the piles above low water is the only part which decays, a method by which only that portion of the pile could be impregnated would remove all the objection to wooden piling except that of the fire risk. Experiments are being made with some promise of success by one of the manufacturers of wood preservative to impregnate the upper portion of the piles for a distance of ten feet or more by lowering a cylinder closed at the top over the pile after it has been driven and cut off, fitting a tight collar between the lower end of the cylinder and the pile and then pumping

the preservative into the cylinder under heavy pressure. Attempts have been made to obtain the same object by boring a vertical hole in the centre of the pile at the top and filling it with preservative. This method, however, failed, as the preservative did not spread radially from the hole, but ran down the annual rings in the timber and only impregnated a core about the size of the hole.

Decay can be prevented by creosoting by the pressure process, though some examples are known of the rotting out of the interior of 12-inch square timbers preserved by this method. Such treatment greatly increases the cost of the lumber, and it is not usually considered economical to use creosoted material for wooden wharves except in places like the foundation for shed posts, where it cannot be easily renewed. Treatment by the dipping process is cheaper, but still expensive on account of the equipment and handling required, and is open to the same objection as the pressure process in that the cutting of the lumber after treatment leaves portions of the material exposed to decay.

That portion of a wooden wharf which is subject to rot, decays most rapidly at the points where moisture enters and does not dry out, such as at butt joints and where one timber bears on another. A brush coating of good preservative on all scarfs, butts, tenons, tops of rangers and stringers, and all other places where one timber rests on or against another and on all timber within five or six feet of the edge of a wharf or pier where it is exposed to spray and rain, is cheap, greatly increases the life of the timber, and makes the deterioration more uniform.

One advantage of treating lumber is that the cheaper grades, containing a large amount of sap wood which, though it is nearly as strong as the heart, decays much more rapidly, can be made as durable as the more expensive grades.

Concrete enters largely into the construction of piers and wharves. It has the advantage over wood in that it is not subject to decay or destruction by fire or marine borers.

Up to the present time there has always been considerable uncertainty as to the durability of concrete in sea water, as there have been many failures and many successes and the reasons for success or failure have not in all cases been ascertained. The present-day knowledge of the subject may be summed up as follows.

Well-made concrete which is constantly submerged in sea water and which has not been exposed to the washing action of water currents until it has hardened will not disintegrate.

Most of the deterioration of concrete in sea water takes place on the exposed surface between high and low water in cold climates and is due principally to frost and the crystallization of salts and in less degree to the abrasion of floating timber and ice and to the action of waves. Such deterioration may be easily and cheaply repaired by means of the cement gun or by properly secured patching.

Disintegration can be largely prevented if sufficient care be taken in the selection of the cement, sand, and stone, in the mixing, depositing, the construction of the forms and the prevention of the action of waves or currents on the concrete before it is hard. The cement should preferably be low in alumina, and the sand and stone should be graded in size so as to give the densest and most impervious mixture possible, in order to prevent the entrance of the water into the mass and the consequent disruptive action of the frost and the crystallization of the salts from the sea water. This impermeability of the concrete is the most important element of durability and has been successfully attained by the use of a large proportion of cement. One part of cement to one and one half parts of sand have given excellent results, while those with one part of cement to two parts of sand and more appear to be uncertain.

Much greater reliability can be obtained by moulding the concrete on land, as is the case in concrete piles and in the great blocks of the New York bulkhead wall, than by depositing it in forms below high-water mark, where it is

difficult to prevent the washing action of the water before it has time to harden. Concrete deposited under water by tremie has in some cases been successful, but the difficulties in obtaining good work are numerous and there are so many examples of unsuccessful results following the use of this method that it is generally considered undesirable.

Concrete Piles. — The use of concrete piles and columns has made great strides within the past decade for situation where great permanency is desired and the marine borers render the use of timber piles, either with or without the use of preservative treatment, inadvisable. This applies particularly to piles. Much progress has been made within the last four or five years in increasing their length and in reducing the cost of fabrication and handling. Piles up to 106 feet in length have been used where hard bottom was at great depth and concrete columns have been placed extending 45 feet below low water.

The reinforced concrete columns mentioned above have been used to a considerable extent on the Pacific Coast, where they originated. They consist of a reinforced concrete cylinder three or four feet in diameter, enlarged at the lower end to give a bearing of great area on hard bottom or a group of wooden piles.

Concrete piles cost from three to four times as much as wooden piles of the same length, but in some places are cheaper than columns of concrete resting on and protecting clusters of wooden piles. They are somewhat wasteful of material, as the strength required for handling them with ordinary appliances is greater than that required for supporting the load after the pile is in place. They will support more load as a column than wooden piles in certain kinds of bottom, but on account of their weight will not support as much as a wooden pile where skin friction is relied upon for bearing power.

Concrete sheet piles of various forms with and without tongues and grooves have been successfully used in many places. They have also been made with the interlocking

portion of steel-sheet piling embedded in their edges, the cracks between the adjacent concrete portions of the piles being filled with grout to protect all portions of the steel from rust. Steel-sheet piles encased in concrete are also used, but are comparatively expensive.

Stone masonry is so costly that it enters very little into the construction of wharves and piers at the present time except as a facing of walls of the most monumental character, such as the New York bulkhead wall, and for protective facing for concrete.

Steel. — Steel for bearing piles and sheet piles has been used to some extent, the latter mostly within the last few years, for wharf construction.

Steel piles made of pipes such as are used for gas and water have been used for the ocean piers at Atlantic City, N. J., Old Orchard, Me., and Coney Island, N. Y., which were built twenty or thirty years ago. These piers are subject to severe wave action, and those at Atlantic City and Old Orchard corroded to such an extent in about ten years that they had to be rebuilt. The superstructures of these piers, as well as the piles, were very severely attacked by the rust. The piles of one of the piers at Coney Island, however, are said to have had a useful life of about twenty-five years.

Steel sheet-piling without any protection except paint has been used for retaining walls for wharves in fresh water, notably in Bremen; at the entrance to the United States lock at Black Rock, Buffalo, N. Y.; at the Barge Canal Terminal at Rome, N. Y.; at Sandusky, O.; Hamilton and Toronto, Ont.; Duluth, Minn.; and in salt water at Jacksonville, Fla. It gives a very simple and cheap form of construction and can be arranged to be easily replaced if rusted to the danger point. The estimated rate of destruction by corrosion is so low that it is claimed that for a structure having an assumed commercial life of thirty to forty years this material is more economical than wood or concrete in fresh water.

The rate of corrosion in water of the commercial steel of the present day is very uncertain and the action of the various factors which determine it are at present not entirely understood. It is known, however, that corrosion cannot take place without oxygen and it is considered that steel buried in the ground, where whatever oxygen there is in the material in contact with the steel is soon exhausted, may be depended on to last indefinitely. Where steel is subject to currents or waves which bring fresh supplies of oxygen to the metal the corrosion is much more rapid than in still water. On the other hand steel in salt water is often covered with a dense growth of shell fish which partially protects it. In most cases the corrosion has been found much greater above low-water level than below it. This portion of a pile, exposed to alternate wetting and drying, can, like the sides of a ship, be protected by painting, but the expense would be considerable. In most cases it has not been attempted and in others it has failed because the waves and spray washed the paint off before it had time to harden. It is well known that the rate of corrosion is much greater in salt than in fresh water, and it has also been ascertained that steel bars of different shapes have different rates of corrosion. A paper by B. H. Thwaite, an English engineer, published in 1880, gives as the result of experiments the following comparative rates for the corrosion of steel:

Foul sea water	.1944
Clear sea water	.0970
Foul river water	.1133
Pure air or clear river water	.0125
Air of manufacturing districts or sea air	.1252

The above figures are the "coefficients of corrosion" to be used in the formula $Y = \frac{W}{C\,L}$, where Y is the life of the metal in years, W the weight in pounds per linear foot of steel bar exposed, and L the perimeter of the steel bar in feet.

A steel plate $\frac{7}{16}$ inch thick, 12 inches wide, has a weight of 17.85 pounds per linear foot. If we assume that only one side of this plate is exposed to sea water, the perimeter so exposed would be one foot. Taking the highest coefficient given in the table the formula for the life of the plate would be $Y = \frac{17.85}{.1944 \times 1} = 91 +$ years. A steel-sheet pile with a web $\frac{7}{16}$ inch thick, with one side protected by filling, as it would be in a retaining wall or a tubular pile filled with concrete, might be expected therefore to last according to the formula for some 90 years in still water before the tube or the web of the sheet pile is entirely destroyed. From this some estimate may be made as to how long such piling would last before it became too weak to bear the stresses imposed on it.

The wreck of the U.S.S. *Maine* submerged in the harbor of Havana for thirteen years affords considerable information on this subject. This ship was built of modern steel in 1895. When the wreck was exposed to view in the cofferdam built for the purpose it was found that all steel which had been covered with mud showed only a thin coating of rust. The portions which were totally immersed in water were only slightly corroded, while those at and near the surface were very much eaten away. Steel in contact with or in proximity to brass or copper was destroyed by electrolytic action. All paint below the water surface had totally disappeared and all submerged metal above the mud line was covered with a dense coating of shells and other marine growths. Havana harbor has only about 18 inches of tide and almost no currents, and the stillness of the water and the coating of shells probably account, in part, for the remarkably good condition of the steel.

Cast Iron. — Cast iron has been used in wharf construction in the form of columns or cylinders in many places, and while expensive in first cost has been generally successful. The steamboat pier at Old Point Comfort, Va., was

built on cast-iron piles one inch thick, which are said to be in good condition after thirty-two years of service, though the steel superstructure is badly corroded.

Riprap, or "one man stone," if it can be obtained cheaply, as in New York, where the price, put in place from scows, varies from 50¢ to 70¢ a cubic yard, enters largely into the construction of wharves and piers and has a decided influence on the design.

When used alone as a retaining structure it does not afford the vertical face required in a wharf, but when combined with masonry walls, sheet-piling, or platforms it has many advantages. It is also used to stiffen the piles in piers and marginal wharves where the water is more than 25 feet deep, also to consolidate soft mud, to distribute pressure of walls on soft bottoms, and to prevent the erosion of earth banks by waves and currents. It is a fact not generally known that piles can be driven through freshly deposited riprap from 20 to 30 feet, provided that the piles are properly shod and that the fragments of stone do not exceed 16 inches in any dimension.

Concrete *vs.* **Timber.** — Concrete and timber are the materials which today hold the first places in wharf construction.

As the prices for piles, lumber, and concrete materials vary greatly according to locality, the relative economy of timber and concrete can only be determined by comparative designs and estimates of total cost for the commercial life of the structure, as indicated on page 238. As the cost of such designs and estimates bears only a small ratio to the cost of a large wharf or pier, it is well worth while to work out a number of them for each case and if possible obtain actual bids on them.

Generally speaking, the first cost of concrete is greater than that of timber for the superstructure, and concrete piles cost two or three times as much as those of creosoted timber and three or four times as much as those without preservative treatment. A rough comparison of the cost

of timber and reinforced concrete of the same volume may be obtained from Table II.

The cost of the piles in a pier usually amounts to considerably more than fifty per cent of the total cost of the structure and in this item may be found one of the greatest fields for ingenuity and originality in design. Great economy may be obtained by the use of a combination of the two materials, in which the portion of the piles subject to decay and the attacks of marine borers is made of concrete and the portion below the harbor bottom which is not subject to destruction from these causes is of timber. Such combination piles have been used in a number of cases, notably at San Francisco and Bocas del Toro, Panama, as described in a subsequent chapter. Wooden piles protected with a coating of cement mortar have been successfully used at Port au Prince, Haiti, and at San Juan, Porto Rico.

TABLE II

COMPARISON OF COST OF EQUAL VOLUMES OF CONCRETE AND LUMBER

Cost of Concrete in place		Equivalent price for lumber in place per 1000 ft. B. M.
cu. yd.	cu. ft.	
$6.00	$0.22	$18.52
7.00	0.26	21.61
8.00	0.30	24.69
9.00	0.33	27.78
10.00	0.37	30.87
11.00	0.41	33.95
12.00	0.44	37.04
13.00	0.48	40.12
14.00	0.52	43.21
15.00	0.55	46.29
16.00	0.59	49.38
17.00	0.63	52.47
18.00	0.67	55.56
19.00	0.70	58.64
20.00	0.74	61.73

CHAPTER II

PRIMARY PRINCIPLES OF DESIGN

Commercial Life

In the economical design of wharves and piers an estimate of the commercial life of a structure is of the first importance. In most places experience has shown that traffic shifts from place to place and that localities may become obsolete as far as their desirability for wharves and piers is concerned. Entire industries die out and new ones take their places, and new methods and machinery are adopted for handling freight and for construction work, making it uneconomical to spend money for great permanence of construction where permanence of usage cannot be definitely foreseen.

An example of the change due to improved mechanical devices is found in the building of piers on the North River in New York City. The earlier piers were built of the crib-block and bridge type on the shores of the East River, where there was a suitable bottom, in spite of the swift currents. These piers could be built entirely with hand tools and did not require any pile driving, which, with the hand-power drivers of those days, was slow and expensive. With the development of the steam-power pile-driver it became possible to build pile piers economically, and the North River front, with its soft bottom, greater width, and slower currents, was utilized.

Another example showing the changes due to the size of ships and shifting of trade centres is found in the Chelsea district of New York. About 1840 the river was filled in for a distance of 1500 feet out from the shore. Streets

were laid out and large factories built on the land thus made. About 1880 a demand arose for longer piers for the Atlantic passenger ships, but the narrowing of the channel by the lengthening of the piers was forbidden by the United States authorities. It was found, however, that at the prevailing rates of rental it would pay, with the use of modern dredging machinery, to remove the filled-in land for a distance of 500 feet inshore, together with the factories and other buildings and to construct piers 800 feet long. This was actually done and the improvement completed in 1909, about seventy years after the land was originally filled. In the Brooklyn Navy Yard a large artificial island was built and partially removed and replaced with piers within half a century. Numerous other examples of changes in less than fifty years might be quoted, particularly in Europe.

These and similar experiences have led the engineers of the New York Dock Department to consider that it is not profitable to spend money for permanence of piers in excess of that required to give them a life of about forty years. In designing a state-owned pier, recently built, only twenty-five years have been allowed as the commercial life of the structure. In another city, on the other hand, estimates of the economy of methods of construction ensuring great durability have been based on a life of one hundred years. The fallacy of basing a comparison of the economy of permanent and semipermanent types on an assumed commercial life of one hundred years is shown by the rarity of wharves that have been in use for such a length of time without outliving their economic usefulness.

Comparative Estimates of Cost. — Having decided on the number of years to be allowed as commercial life of a proposed wharf, in order to determine the relative economy of various designs involving variations of cost and durability, the total cost of the proposed structure together with the cost of borrowing the money for building it should be estimated. Such an estimate should include as many

of the following items as may apply in each individual case:

1. First cost of the structure or equivalent sinking fund charges.
2. Interest on the first cost.
3. Charge for physical depreciation involving loss of earning power.
4. Charge for obsolescence involving loss of earning power.
5. Fire insurance.
6. Insurance against loss of income from fire.
7. Loss of income during repairs, renewals, or alterations.
8. Annual average charge for repairs or charge at stated periods.
9. Operating expenses.

All these items except the first may be estimated on the annual average. If this is done all except the first should be treated as annuities and their total cost should be calculated as that of the sum of annual instalments plus the compound interest on them. This is given by the formula

$$A\,\frac{(1+r)^{n-1}-1}{r}$$

in which A is the annual instalment, r the rate of interest, and n the life of the structure in years. An annual average for repairs and depreciation may in some cases be replaced by percentages of the cost of various parts of the structure at the end of stated terms, as indicated in Table I. In such cases they should be treated as investments at compound interest for the remainder of the life of the structure.

The items for insurance against loss of income from fire and for interruptions of income during repairs or renewals are somewhat unusual, but they may easily, under some arrangements of rental, be of great importance.

If the life of the bonds is greater than the estimated life of the structure, then the sinking fund must be such as to produce a sum at the termination of the life of the structure

which, if invested in other securities, will pay off the bonds when they are due.

Of course when capital is limited it is not always possible to utilize the most economical design, as outlined above, and the question is changed from how to build the most economical wharf, to how to build the most economical wharf of the required size for the amount of money available.

Growth of Ships

Another most important consideration in designing is the probable growth of ships. Not only have the Atlantic passenger and freight liners grown from the 425-foot *Scythia* of 1874 to the *Aquitania* and *Vaterland* of the present day, with a length of over 900 feet and a draught of 35 feet, but the size of all vessels has increased wherever the depth and width of channels in harbors and canals has permitted. That this applies not only to the great passenger ships but to the ordinary freighter as well is shown by the statistics of the Suez Canal. In 1875 the average gross tonnage of the vessels passing through it was 1969, in 1900 it was 3981, and in 1911 it had increased to 5115. These increases followed the increase of the depth of the canal, which previous to 1890 allowed the use of vessels drawing 24 feet 7 inches, from 1890 to 1902, 25 feet 7 inches, from 1902 to 1906, 26 feet 3 inches, in 1906, 27 feet, in 1908, 28 feet. In 1915 it was expected that 31 to 32 feet draught would be allowed. While there will always be many ships of small size and draught, built to go into the more remote and less important harbors, it is usually the rule that the larger the ship the lower is the cost of transportation and in consequence channels are artificially deepened, canal locks enlarged, and a demand created for increase in the length and width of wharves and piers and in the depth of water alongside them.

Marginal Wharves *vs.* Piers

In making the design for a general plan for the development of water-front property the question as to whether the wharves shall be of the marginal or projecting type is usually determined by the local conditions. Marginal wharves are required in narrow rivers or in those in which the velocity of the current is excessive. For a given length of water front, however, piers placed at right angles to the shore line give greater length of wharfage room in relation to the length of the water front than any other arrangement. For example, a marginal wharf 2000 feet long will accommodate only four 500-foot ships, but on such a property may be built five piers, each 1000 feet long and 150 feet wide with slips 250 feet wide between them which would provide berthing space for twenty ships. Where the water-front property has a high value per linear foot the economy of the latter arrangement is evident.

Where there is not sufficient distance between the shore line and the line limiting the distance to which piers are permitted to extend, for piers of the required length to be placed at right angles with the shore, they may be placed at an acute angle with it. While this arrangement gives longer piers inside a given pierhead line, and makes it easier for vessels to enter and leave the slips, especially in narrow waterways and swift currents, it allows of less useful wharfage room per foot of water front for piers of a given width, increases the cost of the piers on account of the angular construction, and wastes deck space.

Under certain conditions it is desirable to place a marginal wharf at a distance from the shore. Such structures may be shaped like the letter *T* or may be joined to the shore at one end. The T wharf of the Quartermaster's Department at Governor's Island, New York Harbor, is a good example. In this case there was a masonry sea-wall already built, and as there was no occupancy of the water-front property there was no reason for economizing on the

length of water front required for the pier. A filled-in marginal wharf extending to water of sufficient depth would have obstructed the swift tidal currents. A pier at right angles to the shore would have required expensive dredging in the hard bottom or, if of sufficient length without dredging, would have extended into very deep water and would have obstructed the very congested waterway. The problem was solved by building a pile wharf parallel to the shore at a point where the water was sufficiently deep and connected to the shore at the middle by a roadway of similar construction.

Dimensions of Wharves

The length of a pier is usually determined by the nature of the vessels it is designed to accommodate and the local conditions, such as the pierhead and bulkhead lines established in all harbors under improvement by the federal government.

The width of a wharf should be sufficient to allow for the economical distribution and collection, the sorting, inspection, and temporary storage of the freight. The economical width is also affected by the front-foot value of the property on which the wharf is located.

In order that the time required to load and unload a vessel may be reduced as much as possible, the wharf area to be provided for each vessel berthed at the wharf is that necessary for the storage of an entire inbound and outbound cargo less the amount of cargo that can be brought to and taken from the wharf while the vessel is loading and unloading and less the amount that can be transferred directly between the vessel and cars and lighters.

The freight-holding capacity of a given area varies in proportion to the depth to which the freight is piled, and the area required to afford a given capacity would be greatly affected by the presence or absence of tiering machines or overhead travelling hoists.

As the rate at which freight can be transferred between the wharf and the ship does not vary in proportion to the capacity of the vessel, it usually follows that the smaller the ship the nearer the minimum wharf area required approaches that required for storing an entire inbound and outbound cargo.

The cost of collecting and distributing freight on the wharf depends largely on the horizontal distance it has to be transported, and it is evident that in order to reduce this distance to a minimum the width of the wharf should be such that the area provided for each vessel should be located abreast of the vessel and for a short distance ahead and astern.

A width of from 80 to 150 feet has usually been considered sufficient for ordinary steamship service, but both in foreign and domestic ports the tendency is to provide greater width, and piers up to 400 feet in width have been built, for large vessels, in this country. An example is shown in Fig. 71.

It is stated that the present practice in Hamburg is to provide a shed 200 feet wide for each ship. For a pier this would require 400 feet of width of shed in addition to roadways and railroad tracks.

The width of the slips between piers should be sufficient to provide for fenders on the piers, for ships lying at the piers, for lighters lying between the ships, and, in places where it is required that large passenger ships be coaled at a rapid rate, for coal barges to lie between the ships and the piers. The tendency to make the slips too narrow in order to increase the number of piers on a given length of water front has been the cause of much congestion in places where the use of lighters is common.

The elevation of the decks above mean high water should be sufficient for them to be free from danger of flooding by waves at extreme high tide, and should not be so great as to interfere with the handling of cargo at low tide. In ordinary sheltered harbors the height is usually from 5

to 6 feet above high-water level. In New York, where the mean range of tide is 4.25 feet and extreme tides have risen to 4 feet above mean high water, the decks of nearly all piers and wharves have been placed 5 feet above the latter elevation for half a century or more and there is no tendency to make any change. In Boston, at the Commonwealth piers, where the mean range of tide is about ten feet, the decks are 8 feet above mean high water. At Halifax, on concrete pier No. 2, with 6 feet of tide the deck is 13 feet 2 inches and the railroad tracks on the pier 9 feet 8 inches above high water. In Philadelphia, with 6 feet of tide, the decks on the Municipal Wharves are 6 feet above mean high water. In Havana two double-deck steamship piers have the lower deck at 5 feet 8 inches and the upper deck at 29 feet above mean low water, but the maximum variation of the water level is only 18 inches.

Live Loads

The live load to be provided for in designing wharves varies from 75 pounds per square foot for those designed for handling passengers only, to 1000 pounds for heavy freight. It is difficult to prevent overloading by such heavy materials as pig lead or materials which are easily piled to a great height, such as sugar in bags, tin sheets in boxes, or sand and broken stone. Many wharves have failed from overloading, especially where they have deteriorated from age and decay. A heavy live load should be provided for rather than a light one.

Table III shows the live loads provided for by several important wharves.

Tidal Prism

One of the requirements of all wharf construction in tidal harbors is that it shall not diminish what is known as the tidal prism. This is defined as that body of water between mean high and mean low water levels, which enters and leaves a harbor with each tide. It is relied on

TABLE III

	Live load — lbs. per square foot	
	Lower deck	Upper deck
N. Y. Dock Dept. Piers	500	350
N. Y. Dock Dept. Bkhd. Wall	1000	
Havana Steamship Docks	250	400
Halifax — Concrete Pile Pier No. 2	1000	500
Philadelphia — Municipal Wharves	600	300 and 400
San Francisco — State Piers	500	
Baltimore — Municipal Wharves	600	
Tampico — Oil Dock	800	

in many places to scour and maintain the channels in the harbors and those across the bars at their entrances. Any diminution of this prism tends to make the channels shallower and adds to the expense of maintaining their required depth by dredging. This is taken into consideration by the federal authorities in fixing the bulkhead line or outshore limit for solid filling which, together with the pierhead line or outshore limit of structures of any kind, is established in all harbors under the jurisdiction of the Secretary of War, where it is required by the local conditions.

CHAPTER III

DETAILS OF TIMBER CONSTRUCTION

Piles and Pile Driving

Piles up to 60 feet in length are easily obtained on the Atlantic Coast, of spruce, white pine, oak, Norway pine, or short-leaf pine, the latter material supplying the bulk of the demand. Piles of 60 to 85 feet in length are usually of long-leaf pine; they are somewhat difficult to obtain and are rapidly increasing in price; piles over 85 feet in length are not generally on the market, and where longer piles are required splicing is usually resorted to. Spruce piles are not as durable above water as those of the various species of pine; oak piles are more expensive than those of other woods and are used principally for fender piles or in places where the driving is especially difficult; some cypress piles are also used. Piles of Douglas fir up to 120 feet long, of perfect form, are readily obtained on the Pacific Coast and the promise of delivery on the Atlantic Coast by way of the Panama Canal of fir piles up to 110 feet long, which is the limit that can be carried on the decks of vessels engaged in the lumber trade at reasonable prices, will probably soon be fulfilled.

Pile Formulas. — The impossibility of the universal application of the ordinary formulas for the bearing power of piles has been demonstrated again and again in the deep mud and in some hard bottoms in New York Harbor. Long piles which do not reach hard bottom in the uniform silt of the Hudson River, which under the Engineering News formula are safe for only $4\frac{1}{2}$ tons, are designed for a safe load of 12 tons. In similar material piles have been found

capable a few days after being driven of supporting 35 tons without detrimental settlement.

Steam *vs.* Drop Hammers. — It is a curious fact that, in spite of the known advantages of the steam pile hammer over the drop hammer the former is not in general use by contractors engaged in water-front construction in New York and many other Atlantic ports. The reason for this is not apparent. The steam hammers have been tried by many contractors, but their advantages, for floating pile drivers at any rate, have not been great enough to offset the increased first cost of the equipment and gain for them the general use they have attained in work other than wharf building.

Lagged Piles. — Where the mud is very deep and deficient in supporting power the skin friction of the piles may be increased by lagging the piles with four wooden strips 5 inches by 6 inches in section, fastened on with screw bolts and spikes. The efficiency of this device has been questioned by some, but the experiments of the New York Dock Department are conclusively in its favor and it has been used in many important piers in New York.

Floating Drivers. — Floating pile drivers in which leads similar to those in use on land are mounted on scows are generally used for wharf construction. Besides their special function, they are of great general usefulness. Equipped with a cable on which is placed a trolley, from the top of the ways to some convenient point, they are used for "telegraphing" or transferring piles and timber. A boom with its lower end fitted to a socket in a drop hammer converts the pile-driver into a fairly efficient derrick boat. Many floating pile-drivers are equipped with air compressors for operating wood-boring tools and with powerful pumps for jetting down piles. Special engines, differing from the ordinary machine for use on land, in that they are equipped with two or more pair of extra winch heads, are essential for manœuvring the scow and the rapid and efficient handling of the piles.

Piles are removed with floating equipment by pulling with heavy wire-rope purchases. When these are attached to the heads of the leads they bring very severe stresses on them and unless the latter are very strong they will be bowed out by continued service of this kind. In Boston large derrick scows or lighters are used for pulling piles, a heavy gallows frame being mounted on the end opposite to the engine and derrick. The derrick is used for placing the piles on the deck of the lighter for transportation. In other places so-called "catamarans" are used for the transportation of piles. These are rafts of old white pine timber with strong posts at the corners and along the sides for holding the cargo of piles in place.

Inclined Drivers. — There are several forms of machines and attachments for driving bracing or batter piles. The best floating pile drivers for this purpose are built with a well into which the rear ends of the sills of the leads are lowered, the forward end of the sills being connected to the hull by hinges. Other machines are fitted so that the rear ends of the sills may be raised and the ways inclined forward. The bow of the scow in machines so equipped is inclined instead of vertical, as is customary in most floating drivers. This form has the great disadvantage that bracing piles inclining inward from the edge of the deck of a pier must be driven before the vertical piles. An unusual form is that in which an independent set of hammer ways or guides is hung on a pivot at the top of the tower and is inclined from the vertical by moving the lower end out to either side as required. The most common arrangement, however, is an independent set of short inclined leads lashed to the ordinary standing leads in a plane at right angles to them. This is a cheap rig and is fairly efficient for occasional work where the piles are not too long and the driving not very difficult.

For inclined piles in the interior of a pier a land machine with leads inclined forward from the engine and boiler has been used.

Pile Followers. — Where piles are to be cut off at some distance below low water they are sometimes driven with a follower consisting of a piece of timber or a steel tube joined to the head of the pile by means of a sleeve. This method does not usually produce very good results unless the followers are carefully and very strongly and expensively made. The side strains during driving are very great and the usual home-made rig is defective in size and strength and results in frequent break-downs and unsatisfactory inclination and unevenness of spacing of the piles. This method is also apt to broom the heads of the piles to such an extent as to make it necessary to cut them off in order to properly support concrete or other materials. In places where the tides are not excessive and plane of cut-off not too far below low water it is often cheaper to dispense with the follower and waste a portion of the pile.

Leads which can be extended below the surface of the water to guide the follower are sometimes used and produce better results than when the follower is used without them. A steel tube, of sufficient diameter to contain the pile without binding, driven a short distance into the bottom, has also been successfully used for guiding the follower.

Lateral Support for Piles

Where the depth of water does not exceed about 25 feet the bearing power of ordinary wooden piling of 14 to 16 inches diameter when considered as a column is usually sufficient for loads of from 24,000 to 30,000 pounds, but in cases where the water is deeper the piles need additional support, both for strength as a column and for stiffness to resist lateral forces, such as currents and the impact of vessels and ice. Under such conditions banks of riprap or broken stone, the pieces of which do not measure more than 16 inches in any dimension, and round cobble-stone not exceeding six inches in any dimension, are used for giving the necessary support. The latter material offers less resistance to pile-driving.

The bed of stone may be put in place before or after the piles are driven. In very deep mud where the piles do not reach to hard bottom the stone usually settles and carries the piles with it. If the stone is placed after the piles are driven it has a tendency to arch between the piles and increase the load on them. In such cases it is necessary to provide some means of bringing the structure up to grade after the settlement has taken place.

Where the piles reach to hard bottom through a layer of soft mud the stiffening material should be deposited before the piles are driven or if this is not done great care must be taken in placing it in order that the movement of the mud may not break or displace the piles. A large pile pier in Baltimore was built on this kind of a bottom and after the shed had been built it was decided to place gravel around the piles to give them additional support. Holes were cut in the deck for this purpose, and when the gravel was deposited the weight of the gravel caused the mud to flow laterally from between it and the hard bottom. It was expected that the movement would be equal on both sides of the pier, but it was so much greater to one side than to the other that the mud caused the piles to tip over till they could not carry their load. The result was the entire destruction of a large portion of the pier and shed, the destroyed area containing about 5000 piles.

The lateral support of soft mud and silt is much greater than might be expected, but the extent to which this support may be relied on cannot be calculated and is a matter to be decided by judgment based on local history and experience.

Test Piles and Borings

Thorough examination of the bottom by means of wash borings as well as test piles and a careful study of the geological formation is necessary in most cases. Test piles are unreliable where dredging is to be done unless driven after the dredging. A case occurred in New York where test piles and wash borings were driven to determine the length

of piles for a large pier located on a bottom consisting of layers of sand and gravel, and clay overlaid with mud. After dredging the sites of the piers to a depth of 30 feet at the sides and 15 feet along the centre line it was found that very much longer piles were required than were shown by the preliminary test piles. In this instance the penetration of the piles varied so greatly that it was necessary to drive the test piles 50 feet apart each way.

Details of Construction

The durability of a wooden wharf or pier depends to a very great extent on the care taken in the details of the design to prevent as far as possible decay caused by the wetting of the timber by rain water, horses' urine, condensation, etc. To obtain this end, all places where water, dust, dirt, and rubbish can collect should be as far as possible eliminated. Pile heads where they project beyond the sides of cap timbers should be sloped off; all rain water leaders extending down through the deck should be arranged so that the discharge will not fall on any timber; decks should be crowned and scupper holes provided in stringpieces and in the deck, wider on the outside than on the inside to prevent clogging; countersinks for bolt heads and washers in horizontal surfaces should be filled with pitch and all abutting surfaces should be drawn tightly together with screw bolts in order to reduce as much as possible the penetration of moisture between the adjacent pieces. Places on top of timbers on which dirt sifting through the seams in the deck can collect should be filled up solid with chocks and fillers. Tenons, mortises, scarfs, laps, and all other surfaces of abutting timber should be brush-coated with wood preservatives, and pile heads should be liberally coated with asphaltic cement to make them shed water.

As it is impossible to protect all of the timber from moisture, it is important to make it possible for all portions of the woodwork to dry out as rapidly as possible after becoming wet or moist by providing for a free circulation

of air. The result of preventing such drying by reducing the circulation of air has been described in Chapter I..

The durability of a wooden wharf or pier also depends in a great measure on its stiffness and the care with which the details are designed to make all parts of the structure act as a unit when subjected to horizontal forces or blows and to distribute and disperse the stresses resulting from such forces over as large an area as possible. It is important to oppose all stresses with wood in compression as far as it is possible to do so and not to depend on spikes and drift bolts. The number of joints should be kept as low as possible by using the longest lengths of lumber which can be obtained at reasonable prices.

The rows of piles should be cross-braced as far down as possible, as the deflection of an unbraced pile is that of a cantilever beam and varies as the cube of its unsupported length.

The following description of wooden piers as built by the Department of Docks in New York City is a good example of those in which the above principles are followed out with the greatest thoroughness. (See Fig. 1.)

After the slips alongside the pier are dredged to the required depth and the riprap for the lateral support of the piles deposited in cases where it is required, the piles are driven with floating pile-drivers.

The outer portion of these piers is constructed on what is known as the double-pile row system and the inner portion on the single-pile row system. In the single-row system the piles are spaced about 6 feet centre to centre in each transverse row, with the rows 10 feet apart. The outer three rows of piles are double and the number of the piles in each row is also doubled, making the spacing about 2 feet 6 inches. The double rows are spaced about 23 feet apart. This double-row system is expensive, as it requires extra deep longitudinal "rangers" or stringers between the widely spaced pile-rows, but it provides, with the planking and other bracing described later, an enor-

mously strong head for the pier where the greatest horizontal stresses occur, together with wide spaces for the passage of ice, which at times is very troublesome in this locality, and for sewage, which in many cases is discharged from sewers under the pier at a point near the outer end. The added strength is important in view of the strong currents which occur in the portions of the water front used for shipping.

The piers are designed to carry 500 pounds live load with a loading on each pile not exceeding 12 to 15 tons.

The piles of single-row system are braced transversely with horizontal and inclined planks bolted to the piles, the former being at the elevation of mean low water. The piles are faced off and notched to give a good bearing both vertically and horizontally for these planks. The inner faces of each row of piles in the double rows are faced off and six-inch plank fitted between them, each plank being spiked to every pile. The outer face of the outermost row is similarly planked and is protected against abrasion and still further strengthened by vertical oak sheathing. This planking on the double rows practically forms great vertical girders 10 feet deep rigidly connecting the heads of the piles and greatly increasing their stiffness. In the piers for the largest steamships where floating fenders are used the piles along the sides of the pier are strengthened by extra planking similar to that on the double rows.

Each double row is further stiffened with two inclined bracing piles at each end of the row and the single rows have one bracing pile at one end alternating on the sides of the pier.

Armature plates of $\frac{1}{2}$-inch steel are fitted around the end piles of the double rows, the space beyond them being completely filled with timber accurately fitted together.

The side caps are placed 2 feet 7 inches below the top of the deck and these extend to about 5 feet 9 inches above low tide. These timbers extend from end to end of the pier and are placed at this elevation to prevent scows and lighters of low freeboard from getting under it. In

structures where the side cap has been omitted or placed at the level of the rangers or stringers damage has been caused by such vessels being caught under the deck and ripping it up as the tide rose and by striking the side piles with their square corners when entering the slips and knocking them out. The side caps are secured to the tops of the piles by mortises and tenons and large dock spikes driven at an angle.

The transverse rows of piles are capped with 12-inch by 12-inch timbers with mortises fitted over tenons on top of the piles or with two 6-inch by 12-inch planks notched into the heads of the piles and fastened with screw bolts. The latter are more economical in labor, saving the expensive mortising and tenoning, are lighter to handle, rot less quickly, and are easier to obtain in the better qualities of lumber.

On the cross caps are placed the rangers or stringers. The shed rangers which support the shed posts or columns are laid close to the side rangers and break joints with them and are fastened to them with screw bolts. Interior rangers are placed over each longitudinal row of piles. Alternate rangers extend from end to end of the pier and the others over the double-pile row only. Over the double-pile rows the interior rangers are 12 inches wide by 26 inches deep formed by one 12 by 12 inch and one 12 by 14 inch stick or by two 12 by 12 and one 2 by 12 fastened together with screw bolts and spikes and notched down over the caps 2 inches to prevent sliding. The rangers over the single-row system are of 12-inch by 12-inch sticks or two 6 by 12 planks bolted together with $\frac{1}{2}$-inch washers between them to allow for air circulation. When made of 12 by 12 lumber the rangers are bolted and fish plated to take stresses in compression. The joints are placed between pile rows, as it is difficult to find room for a good arrangement of fastenings if they are located over the cross caps. Those made of two pieces simply break joints over the caps. All rangers are fastened to the cross-caps with dock spikes driven at an angle. Over the double rows of piles, chocks

or fillers are carefully fitted between the rangers, making a solid mass of wood from side to side of the pier over each cross cap.

On the rangers and at right angles to them is laid a deck of 4-inch plank, and on this a sheathing or wearing surface of 3-inch plank. The deck planks are spaced 2 inches apart except over the cross-caps and chocking between the rangers, where, in order to prevent dirt which sifts through the sheathing from lodging on the timber, holding moisture and inducing rot, the deck planks are laid close together. Fillers are fitted for the same purpose between the deck planks where they cross the rangers. The sheathing plank on the sides of the pier is laid at right angles to the deck planks, but in the middle, where the team traffic is heaviest, it is laid at an angle of 45° to give better wear and better foothold for horses. When laid at an angle in this manner it also strengthens the deck, making it act as a great horizontal girder. Wire spikes are used for fastening the sheathing on account of their cheapness and the facility with which they are driven. Bright wire nails do not hold as well as cut nails for this purpose, but this objection is overcome if those coated with varnish or cement are used, or if they are rusted by immersion in salt water before driving. As the sheathing wears out and has to be renewed it is not continued under the backing log or shed sills, long lengths of 3-inch by 12-inch plank being laid under these timbers to bring them up to the height of the sheathing.

"Backing logs" of 12-inch by 12-inch timber are placed on the edges of the pier. These were formerly required by law on all wharves in New York City to prevent carts and trucks from backing overboard, and the custom has prevailed until recently. Such a timber interferes seriously with handling freight by means of the longshoreman's hand truck between the wharf and vessels which have their decks lower than that of the wharf. A timber of this height is unnecessary on the parts of piers which are covered by sheds and may be replaced with one six inches high which is

sufficient to prevent men slipping overboard when handling mooring lines.

The fender system consists of white oak piles which resist abrasion better than pine, driven at each end of the cross rows of piles and at the outer corner. The piles are faced off to give a good hearing against the adjacent timber and the tops are sloped off to allow the water to run off and are painted to prevent rot which starts at the top. Covering the tops of the piles with zinc or copper for this purpose is effective where they can be protected from the depredations of thieves. In some places, where the nature of the shipping requires, the fender piles extend 4 or 5 feet above the deck. Between the fender piles are fitted horizontal chocks, and in the 23-foot bays vertical chocks are fitted between the latter. The object of these is to prevent the guard wales of tugs and similar vessels having considerable sheer from catching under the horizontal chocks. Where it is practicable the upper horizontal chock is replaced with a fender pile cap, which holds the piles against displacement and covers the tops and keeps them dry.

The corner fender for light piers shown in Fig. 2 has, to a large extent, been abandoned. The heavier design shown is now standard and a still heavier construction is used on piers for very large steamships. The rounded corner facilitates the docking of long vessels, but the additional piles obstruct the free passage of ice in the outer bays. As corner fenders are often subject to heavy wear the piles are held in place by chains, rather than by bolts, to facilitate replacement.

Foundations for shed posts for single-story sheds are provided by extra piles either in the pile rows or just outside of them. Foundations for two-story sheds require a cluster of piles. They are cut off at 2 feet above mean low water and are capped with timber to support a concrete pedestal.

The types of mooring posts and bitts or bollards are shown in Figs. 124 and 125. They are fastened down with

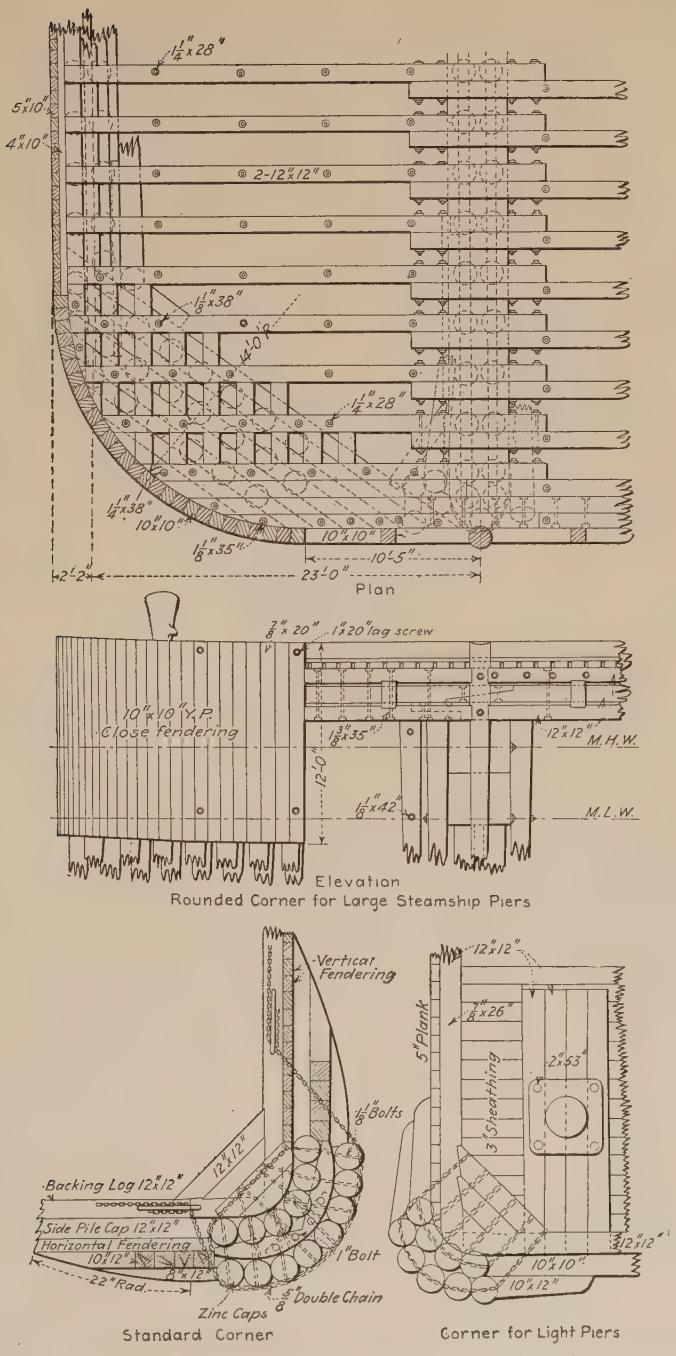

Fig. 2. Corners for Wooden Piers, Dept. of Docks, New York, N. Y.

long $1\frac{1}{2}$-inch screw bolts extending through as many thicknesses of timber as possible, the spaces between the timber being carefully chocked. Special foundation timbers are provided for the large mooring posts at the end of the pier, and the rangers over them are held down by strap bolts.

Heavy iron straps are fitted around the backing log at the outer corners of the pier.

In many piers on the Pacific coast 4-inch by 14-inch joists have been used in the place of the rangers described above. Such joists have not as much strength considered as columns as the 12-inch by 12-inch rangers unless their lower edges are braced against buckling by means of what is known among house builders as "bridging." They require more spikes for fastening to the caps and more nails in the deck planks and consequently a considerable increase in labor, but they permit of the use of lighter deck plank. They have a distinct advantage, however, when required to be creosoted, as they can be completely impregnated much more cheaply than the heavier timbers, but on account of their large surface area and small cross-section they are much more easily destroyed by fire.

Iron and Wood Fastenings

Iron and wood fastenings for lumber in wharves consist of drift bolts, screw bolts, dock spikes, nails and treenails. Iron and steel spikes and bolts last a long time submerged in salt water when protected by wood, provided they are of ample cross-section, but rust rapidly where exposed to waves and currents. It is the practice of the Bureau of Yards and Docks of the U. S. Navy to use galvanized bolts in all salt-water wharves, but this practice is uncommon in other work.

Wooden treenails of oak or locust last indefinitely when kept submerged in water and are useful for fastenings which cannot be easily renewed. The timber portion of the New York bulkhead wall contains no iron whatever,

all parts being fastened with treenails, some of which are 3 inches in diameter and 4 feet long.

Square dock spikes such as are shown in Fig. 3 require

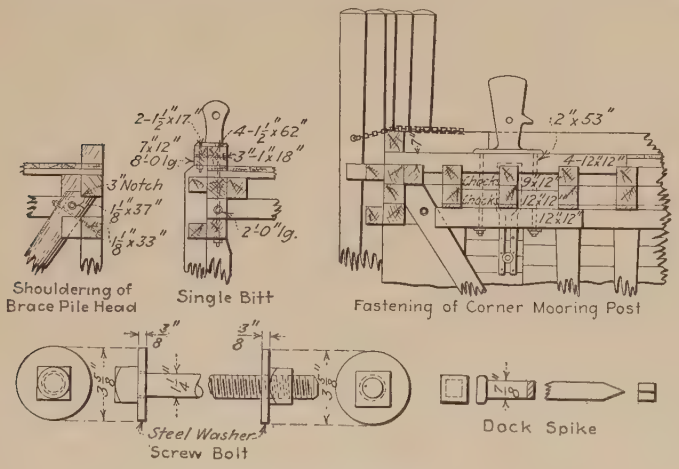

Fig. 3. Details of Wooden Piers, Dept. of Docks, New York, N. Y.

less boring than drift bolts, hold better, and do not add much to the cost of a structure.

Various devices for fastening fenders and similar timber to concrete are used. A sleeve nut such as is commonly used in bridge building is inexpensive and when arranged as shown in Fig. 4 allows of a deep and positive anchorage

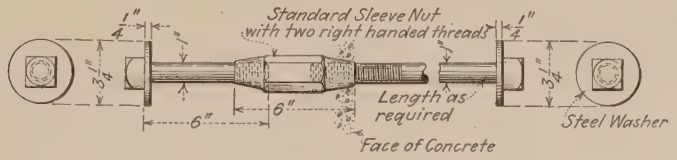

Fig. 4. Bolt for Fastening Fenders to Concrete Walls.

in the concrete and permits the easy removal of the bolt. Expansion bolts have the advantage of not having to be held in place in the forms, and as the holes for them need not be drilled till after the wood is bored there is little time

lost in locating the holes. They are better for stone masonry, however, than for concrete, as the holes need not be as deep. For concrete the shank of the bolt must be fitted with sleeves. Expansion bolts when properly put in place will hold in tension up to the full strength of the bolt at the base of thread, but it is somewhat difficult in ordinary work to obtain such results.

Sewers in Piers

As it is undesirable to have sewers empty into the slips between piers it is necessary to support them in the substructures, as shown in Fig. 70. Sewer boxes of circular form for pile piers are made of creosoted wood-stave pipe with galvanized iron bands. Hatches should be provided at proper intervals to permit cleaning and inspection. Reinforced concrete pipe also affords a cheap and durable material for this purpose which can be easily and cheaply put in place.

CHAPTER IV

RETAINING WALLS FOR PIERS AND MARGINAL WHARVES

Functions of Walls

For solid-filled piers and marginal wharves a retaining structure is required to support the earth or filling and must afford, either in itself or in combination with a platform of some kind, a vertical face of sufficient depth to permit vessels to lie close alongside. Such a structure must prevent erosion of the shore, withstand the impact of vessels, currents and waves, and resist overturning, sliding, and deformation by the earth or other filling with its surcharge of merchandise.

Calculation of Pressures

A wharf wall presents some features which are not present in ordinary retaining walls on land. These consist in the presence of water on both sides of the structure, the diminished weight of the wall due to its submergence in the water, the variety of materials usually found in the filling, and the variation in the weight of the filling due to the fact that part of it is submerged and part not.

The calculation of the pressures on such walls is therefore complex and subject to many more uncertainties than that of land walls. In some cases it is impossible. The two methods used in the Department of Docks in New York are given by S. W. Hoag in the Proceedings of the Municipal Engineers of the City of New York, 1905, as follows:

"The conditions given are approximate cross-section of submerged or of non-submerged wall, submerged sections

and non-submerged sections of riprap filling and of earth filling, and a surcharge of 1000 pounds per square foot (see Fig. 5).

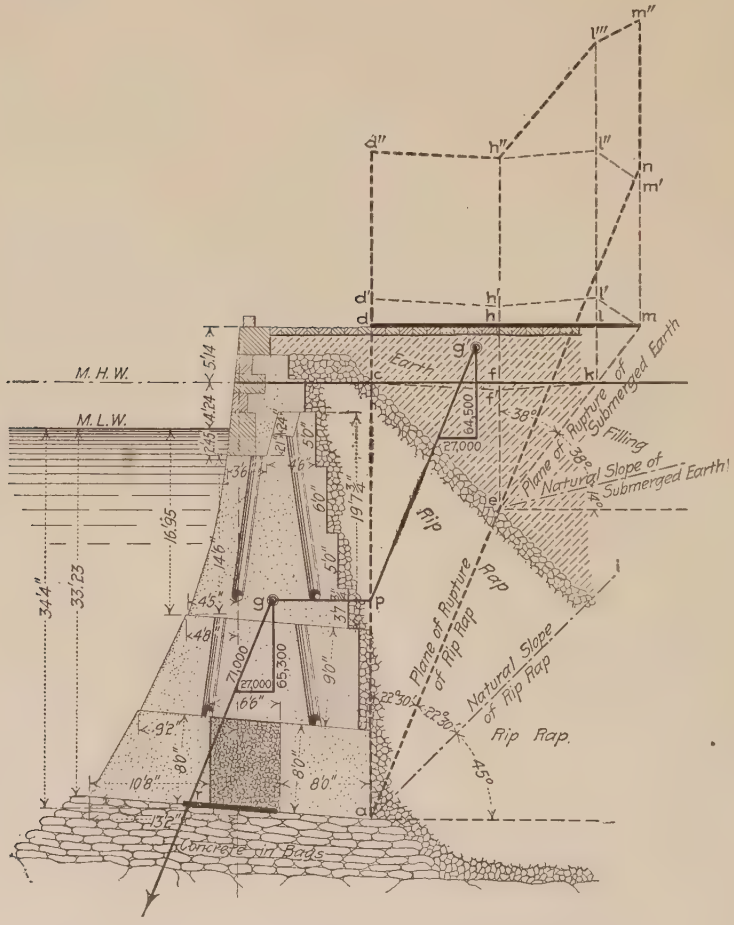

Fig. 5. Method of Determining Pressures in Sea Walls, Dept. of Docks, New York, N. Y.

"Erecting a perpendicular *ad*, laying off the prism of maximum thrust of riprap by the plane of rupture *ae*, prolonging the line *ae* to *n* and the corresponding prism for the superimposed submerged earth filling by the plane *ek*,

which we shall prolong to m, neglecting the change in plane of rupture for non-submerged earth filling, we find that the limit of surcharge to be considered at the surface grade is contained between the intercepts d and m. Considering now everything below mean high water as submerged and everything above mean high water as non-submerged, let us conduct the analysis on the following assumptions:

"Let the weight of riprap in air be assumed at 107 lb. per cu. ft.

"Let the weight of submerged riprap be assumed at 70 lb. per cu. ft.

"Let the weight of earth filling in air be assumed at 110 lb. per cu. ft.

"Let the weight of submerged earth filling be assumed at 66 lb. per cu. ft.

"Let the surcharge be assumed at 1000 lb. per sq. ft.

"*First.* Determine the weight of the submerged earth filling *cek*, and replace it with a corresponding weight of submerged riprap. The top surface of the latter will then be *cf'k*.

"*Second.* Determine the weight of the non-submerged earth filling *cdmk* and replace it with a volume of submerged riprap of equal weight, and allow it to take its position upon the first reduced volume of submerged riprap. The upper surface of this second volume will then be *cd'h'l'mkf'*.

"*Third.* Take the surcharge of 1000 lb. per sq. ft. and erect upon the top surface *d'h'l'm* of this imaginary bank of submerged riprap a prism of submerged riprap of such a volume as shall equal in weight the surcharge; the upper surface of this third reduced volume will then be *d''h''l''m'*. We now have the area *a d''h''l''m'nea* representing in volume all of the back filling used in exerting pressure against the wall reduced to one homogeneous material, namely, submerged riprap weighing 70 lb. per cu. ft. But in order to avoid the complication arising from a consideration of the two planes of rupture *ae* and *em*, and as we have already reduced the back filling riprap, let us adhere to the plane

of rupture for riprap, namely, *an*, and shift the material represented by the area *enm* to a new position to form part of the prism limited by the plane *an*; we have, making h'' the new position for $el''l'''$ the new position for kl', and $m'm''$ the new position for *mn*, as the volume to be considered, the weight of submerged riprap represented by the area $a\ d''h''l'''m''na$.

"The centre of gravity of this area is found to be at g', and combining the weight of the mass through g' with its horizontal component, we find the horizontal thrust on the back of the wall to be 27,000 lb. applied at the point *p*. Combining this thrust with the weight of the wall represented by the vertical line 65,300 lb. through its centre of gravity, we obtain the resultant, 71,000 lb., which passes through the base at the point *r*.

"In determining the centre of gravity of the wall section it is of course necessary to consider the reduction in weight due to displacement below mean high water of the two materials, concrete and granite, which enter into its construction, the weight of the non-submerged portion above mean high water, the weight of the submerged riprap on the steps in the rear of the wall, the weight of the superimposed volume of non-submerged riprap and of earth filling."

The other method, which may be simple in cases where riprap does not form part of the filling, is illustrated in Fig. 6 and the description is as follows: "Applying the analysis to the same section of wall, and laying off the planes of rupture for riprap *ae* and for submerged earth *em*, as before, let us, first, consider the pressure of the volume represented by the area *enme* with its superimposed surcharge. Combining the centres of gravity of the three different densities represented, that is, the submerged earth filling *efk*, the non-submerged earth filling *fhmk*, and the surcharge *hm*, 13,600 lb., we obtain the resultant weight, 23,800 lb., through the resultant centre of gravity g'''. Combining this weight as a vertical force through g''' with its horizontal component, we get the

resultant thrust on *eh*, from which we obtain the horizontal thrust, 18,000 lb., against the vertical plane *eh* at the point *p*.

"Again, in the area *bdhe* combining the weights and centres of gravity of the different materials, namely, submerged riprap *bce*, submerged earth filling *cfe*, non-submerged earth filling *cdhf*, and superimposed surcharge *dh* equal to 12,000 lb., we obtain the resultant weight 28,600 lb. through the resultant centre of gravity *g''*. Combining this force with the horizontal thrust 18,000 lb., we obtain the direction of the resultant which strikes the line *ad* at the point *p''* with a horizontal thrust of 18,000 lb.

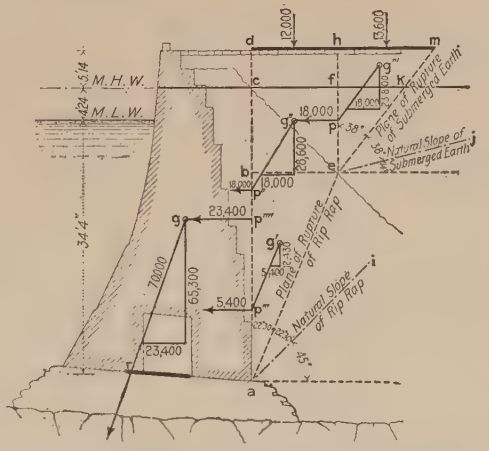

Fig. 6. Earlier Method of Determining Pressures in Sea Walls.

"Finally, determining the weight and centre of gravity of the submerged volume of riprap represented by the area *abe* and decomposing the resultant thrust with this weight 12,430 lb. as the vertical component through the centre of gravity *g'*, we obtain the horizontal thrust 5400 lb. applied at the point *p'''*.

"Now combining the two horizontal thrusts at *p''* and *p'''*, determine the resultant horizontal thrust 23,400 lb. applied at a point *p''''*, and combining the resultant horizontal thrust with the weight of the wall, determined as before through its centre of gravity *g*, we get the resultant thrust on the base of the wall 70,000 lb. applied at the point *r*."

A comparison of the two methods shows a very close agreement both in the amount, direction, and point of application *r* of the resultant thrust.

Another good article on this subject may be found in Merriman's American Civil Engineer Pocket Book.

The horizontal resistance of sheet piling in earth is a subject on which there is little in engineering literature in the English language, but the matter is well treated in an article by Professor Wolmar Fellenius in Engineering Record of Sept. 20, 1913. This article also treats of wharf walls of the platform type.

Mud Waves. — Wherever there is mud which can move as a fluid behind a retaining structure the filling will produce a wave or elevation of the surface of such material. Mud acts like any other fluid against a retaining structure except that it exerts a pressure greater than water. It has no angle of repose and therefore will exert a much greater pressure than earth or any similar non-fluid filling. If filling is deposited on mud from the shore outwards toward a retaining wall it will push the mud wave ahead of it and increase the elevation of the mud pressing against the wall and may thus increase the pressure so much above that of the filling for which the wall is designed as to destroy the structure. This has happened in practice so frequently that the matter demands the greatest emphasis. The remedy is to deposit the filling from the wall toward the shore. In this way the mud is driven away from the wall and the increasing pressure due to the increasing height of the wave is resisted by the increasing width of the bank of filling.

The depositing of the filling in this manner is usually much more inconvenient and expensive than depositing it from the shore outward, in that it is often necessary to construct temporary roadways for the purpose and this may be one of the reasons why this most necessary precaution is so often neglected.

Gravity Walls

Gravity walls may be of riprap, cribwork, stone masonry, concrete blocks, mass concrete, caissons of concrete, steel, or wood, or various combinations of these materials.

Walls which depend on gravity alone for their stability are generally costly as compared to other types, especially where they have to be constructed in the water. Tie-rods and anchors placed in the rear are often used to assist in taking up the thrust of the filling and permit the reduction of the cross-sectional area of the wall. Gravity walls are particularly suited to rock or other hard bottoms where piles cannot be driven. Where the bottom has not sufficient bearing, however, and piles can be driven, a gravity wall may be placed on piles cut off at the proper height. When a wall of stone or concrete blocks is built with a pile foundation some method of obtaining a uniform bearing on all the piles such as is described on pages 90 and 122 should be used.

The outshore face of retaining walls should be sloped back in order to bring the centre of gravity as near the heel as possible, thus increasing the resistance to overturning and decreasing the necessary cross-section. Sloping the face, however, makes it impossible for vessels to lie with their upper parts close against the top of the wall. Where piers for the use of large vessels are built in front of the wall and only small vessels are moored parallel to it, this does not make much difference. For example, in New York City, the slips are narrow and scows and lighters with shallow draught lie at the wall, the large steamships being berthed alongside piers with their bows inshore. The walls are therefore designed with as much slope as is possible with the bows of the steamers coming close up against them. Where large steamers are to lie alongside a wall a nearly vertical face is required, and on a sloping shore it is usually cheaper to place the wall at the rear of a marginal platform, as by such an arrangement its cross-section may be greatly reduced.

Riprap. — A bank of riprap forms a simple form of retaining wall which cannot be overturned and strongly resists movement by sliding. It is often very much cheaper than a gravity wall of concrete or stone masonry. The

sloping sides of such a bank, however, do not permit its use as a wharf unless it is combined with some form of structure which has a vertical face.

Where the depth of water is greater than that required for wharfage such a bank of riprap may be employed to take the greater part of earth-thrust, a masonry wall being

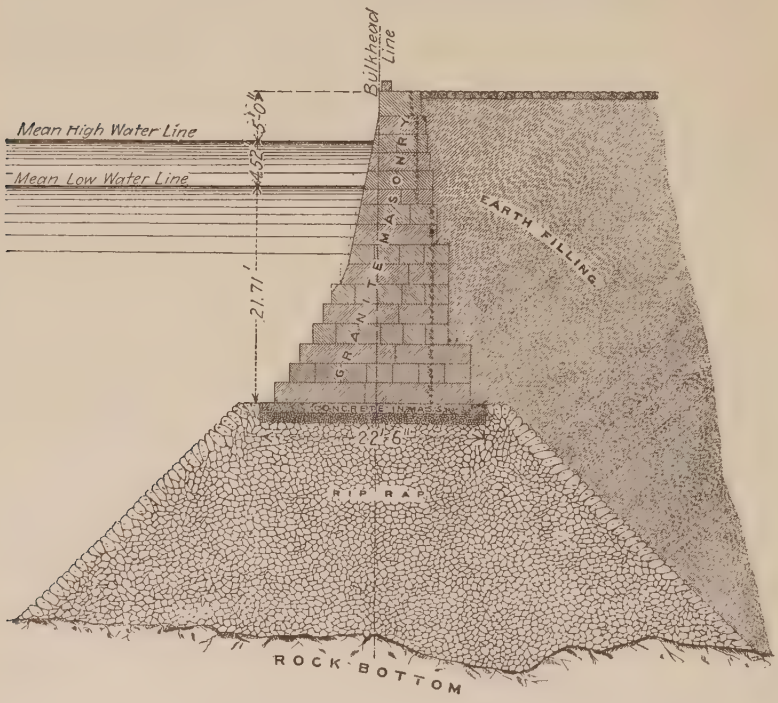

Fig. 7. Riprap Wall with Upper Portion of Granite Masonry, New York, N. Y.

placed on the front edge to provide the necessary vertical face. As this comparatively expensive facing need be only deep enough to serve the requirements of shipping, such a combination results in a large saving over a masonry wall of the full depth. A good example is shown in Fig. 7 built in New York near the Battery about fifty years ago.

When used under a pile platform, a riprap wall reduces

the required width of the platform, takes a major portion of the earth-thrust, reduces the stresses in the bracing piles or tie rods, and gives lateral support and stiffness to the piles. A design for a very inexpensive wall of this type is shown in Fig. 8.

A bank of riprap has a safe angle of repose, when submerged, of 1 on 1 or 1 on $1\frac{1}{4}$, and as this is much steeper

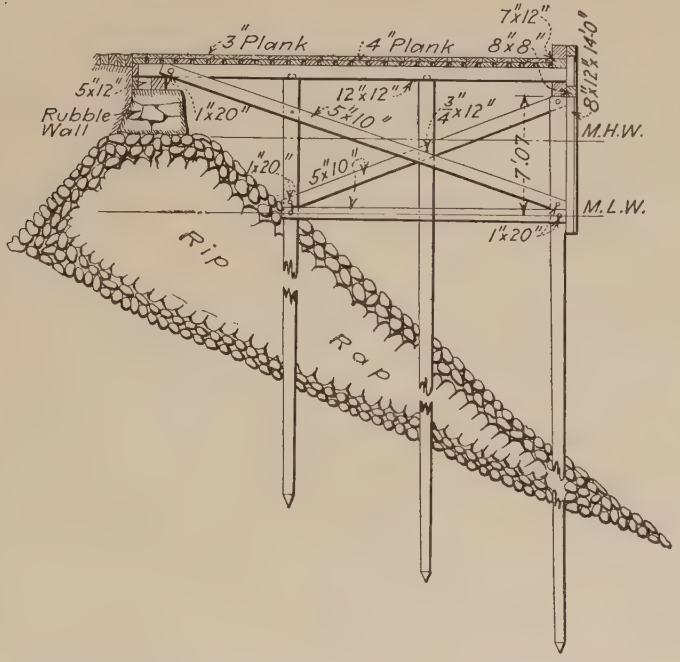

Fig. 8. Design for a Cheap Riprap Wall with Pile Platform.

than the angle of repose of submerged earth, it exerts much less thrust against a vertical surface than other forms of filling. When, therefore, it is placed behind a masonry wall or a line of sheet piling, it reduces the required section of masonry and the stresses in the ties or bracing piles used to support sheet piling. In front of a retaining structure it serves the same purpose, though not so efficiently.

A notable modern example of a riprap wall is that recently built in San Francisco and illustrated in Fig. 9. In this

case the mud was dredged to about 36 feet below low water. The main part of the wall is composed of riprap, as shown in the drawing. A retaining wall of mass concrete 13 feet high, supported on wooden piles 60 feet from the face of the wall, extends from low water to the street level and forms the upper part of the retaining structure, making a smooth and tight coping for the riprap. A platform on concrete piles covers the outer slope of the riprap and forms the wharf at which vessels are moored. In order to provide an elastic deck which would not be injured by the settlement of the riprap and piles in the mud bottom, the beams of the platform are of steel and the joists and deck plank of wood. The wooden piles are protected from the marine borers by the riprap.

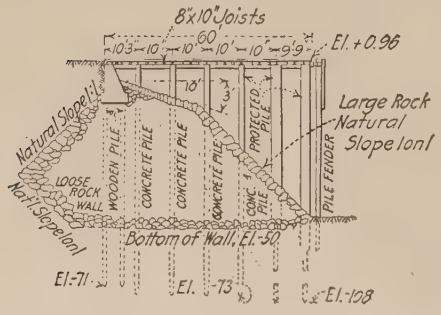

Fig. 9. Riprap Wall, with Concrete Pile Platform, San Francisco, Cal.

The wall built in New York in places where the mud is very deep, described on page 88, is another example of a wall in which riprap plays a leading part.

Cribwork. — One of the commonest forms of retaining structure is that of a stone-filled timber cribwork. Cribwork is best suited for rock or other hard bottom where piles cannot be driven, but has been used on the Harlem River in New York City even in deep mud. In its least expensive form, consisting of a cellular box built of round logs notched together with the axe and fastened with spikes or drift bolts, it is in many localities one of the cheapest forms of retaining structure. In New York it costs about 8 cents a cubic foot, exclusive of dredging. One of its advantages is that it may be built entirely with hand tools and does not require any expensive equipment. It is, however, subject to decay above half tide on the sea

coast and above low-water level in non-tidal harbors, and every twelve or fifteen years the decayed portion must be torn down, rebuilt, and refilled.

A cribwork wall of round logs, as built by the New York Dock Department, is shown in Fig. 10. The structure is built floating in the water, usually over or near the site where it is to be located. The bottom, if of rock, is cleared

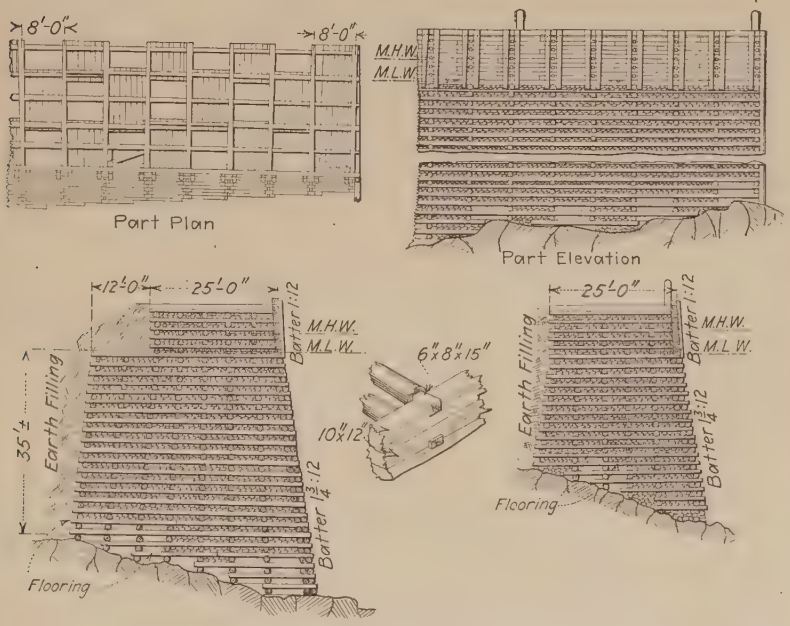

Fig. 10. Crib Wall of Round Logs, New York, N. Y.

of all overlying mud and the cross-section carefully determined. The bottom of the crib is then laid out to fit the surface of the rock. If the bottom is of earth it is dredged as smooth as possible, dredges of the ladder type being superior for this purpose. A layer of gravel or broken stone may be deposited and smoothed off with straight edges to level up small irregularities in the bottom. On sloping rock, sliding may be prevented by heavy iron dowels. The cribs are built with cells 8 feet long and 5 feet wide, a sufficient number of them being floored over.

As the structure is built up, the floored cells are filled with stone and the structure sinks. When it is high enough to reach above low water it is carefully adjusted in location and the sinking of the structure is completed and all the cells filled. As soon as the crib settles and conforms to the bottom the portion above the water is completed. The face is built of sawed lumber above low tide to give a smooth surface and is protected by half-round oak fenders. The longitudinal logs should be not less than 6 inches in diameter at the point and not less than 50 feet long. They should have long laps where they are spliced. The transverse logs should be not less than 10 inches in diameter at the front in the upper portion which is subject to decay and 8 inches in the other portion. Dock spikes of ample size to allow for rust should be liberally used at all intersections. Such cribs usually require a width of not less than 16 feet at the top for heights up to 20 feet and may be from 18 to 25 feet wide for greater depths. The portion below the limit of decay may be made wider than that above, the part which has to be renewed being thus reduced to a minimum.

Cribs of this construction have been used for retaining walls for solid-filled piers in soft mud of great depth, but usually some other form of wall will be found cheaper and more suitable for such locations.

Where appearances are important such structures, if of large section, are usually unsatisfactory. From their very nature they are mere baskets, more or less loose in the joints, and they are liable to bulge both vertically and horizontally, to tip forward or backward, to shrink vertically, and unless the bottom is very carefully prepared they will sink into it more or less.

Fig. 11 shows typical sections of large, round-log cribs, as built by the C. R. R. of N. J. at Communipaw, Jersey City, N. J. They are from 30 to 50 feet deep and are founded on hardpan. In these cribs vertical logs were placed in the corners of the pockets to prevent vertical

shrinkage and the floored pockets are continuous from front to rear, instead of alternating, as in the previous example. Where it was expected that mud would flow into the trench, stone filling was deposited as soon as the dredg-

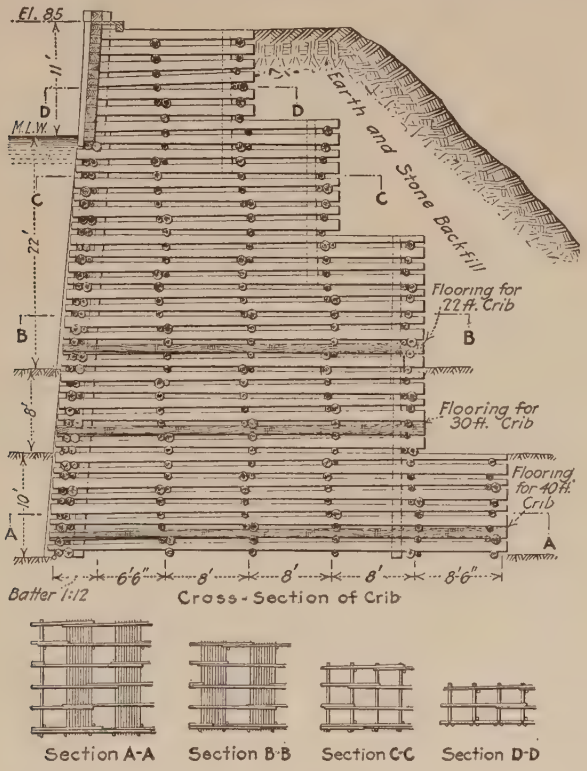

Fig. 11. Crib Wall of Round Logs, C. R. R. of N. J., Jersey City, N. J.

ing was completed and the crib placed on this layer of stone.

On the New York Barge Canal cribwork wharves were built with concrete walls on the outer edge from the water line up, as shown in Fig. 12. A large proportion of the total weight of the structures was in these concrete walls and some of those on ordinary earth bottom tipped forward as soon as the concrete was deposited and kept tipping as

often as more concrete was added. Such action may be partly prevented by supporting the cribs on piles, by making the lowest tier of longitudinal logs continuous, thus increasing the bearing surface, and by temporarily loading the crib with stone or earth and completing the earth filling as far as possible before building the concrete wall.

The lowest tier of transverse logs in these cribs was laid close together and the specifications required that the courses of logs should lay up not less than 10 inches centre to centre and that logs at joints should have two parallel faces not less than 6 inches wide.

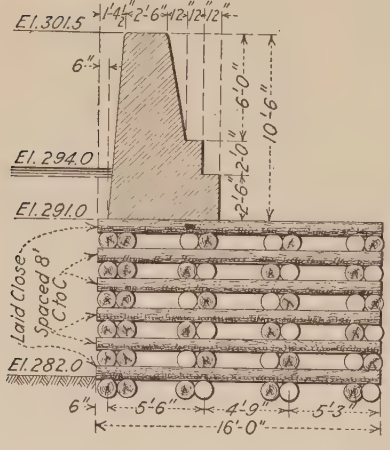

Fig. 12. Crib Wall, with Upper Portion of Concrete, New York State Barge Canal.

More stable cribwork can be made, but with considerably increased expense, by accurately dressing the joints, and still better results can be obtained by using sawed timber for the cross ties or for both cross ties and longitudinals and by bolting vertical timbers in the corners of the pockets.

A crib wall for a large coal pier built at Duluth, in 1909, is shown in Fig. 13. The site of the pier was a sand bank, with its top 6 to 8 feet below water containing layers of clay. The bottom was dredged to a depth of 26 feet for the crib, which was of sawed lumber 21 feet wide with tight front and rear walls of 10-inch by 12-inch timbers and was divided into pockets 6 feet square. The top of the crib was 6 inches below mean low-water level. Piles were driven to support the reinforced concrete wall which surmounted the crib, in order to provide against settlement. The wall was tied to piles driven in the filling 40 feet

from the rear face of the crib by $1\frac{1}{4}$ rods spaced 24 feet apart. This pier carried a heavy surcharge of coal piled on its surface.

The crib wall surrounding an ore-pier shown in Fig. 14 was built at Two Harbors, Minn., at about the same date. The two rows of cribs were surmounted by heavy concrete footing walls resting on piles driven inside the cribs and carrying the columns of the ore bins. This structure is notable for the fact that the work, which included the setting of forms and depositing concrete under water, was done in the winter time in a very cold climate and for the driving of foundation piles at very close intervals in a rockfilled crib. There were two rows of cribs of sawed lumber 16 feet wide placed about 22 feet apart. The cribs were tied together with timber walls, thus making a narrow pier about 55 feet wide. The tops of the cribs were placed at 4.5 feet and the tops of the piles were cut off at 3.5 feet below low water. A sheet of burlap was placed on the top of the piles to prevent the cement being washed out of the concrete. Forms were set on the cribs enclosing an area of about 18 feet by 50 feet and the water inside the forms heated to 45 degrees Fahr. by means of steam under 60 pounds, pressure supplied through a hose. The concrete, mixed in the proportion of 1: 2: 4, was deposited by bottom dump buckets to a height of 6 inches above water. The

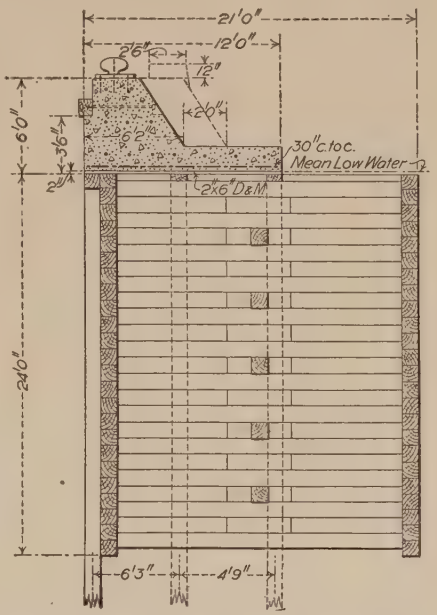

Fig. 13. Crib Wall of Sawed Lumber with Upper Portion of Concrete, Duluth, Minn.

upper portion of the concrete was then completed with a $1:2\frac{1}{2}:5$ mixture. A layer of reinforcement was placed under the bottom of this upper course of concrete, and steel dowels were placed in the lower course to provide a secure bond between the two. The maximum load on the piles under the footings was 24 tons. The space between the cribs was filled with stone to give additional stability and rigidity for the structure, which had to withstand severe stresses from the impact of vessels and from the stopping of heavy ore trains on the superstructure. In this type of pier the function of the cribwork is merely to retain the filling

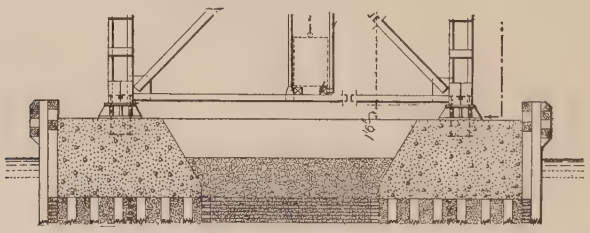

Fig. 14. Crib Wall of Sawed Lumber with Upper Portion of Concrete, Two Harbors, Minn.

which affords lateral support to the piles. In piers of more recent date described further on sheet piling is substituted for the cribwork.

Another type of large, sawed-lumber crib of more recent design, shown in Fig. 15, was built at the Barge Canal Terminal at Buffalo. Here the water was deep and the bottom of rock or hard material. Where there was rock it was levelled off with broken stone. The cribs extended to 22 feet below mean low-water level and on them was placed a layer of concrete blocks extending one foot above the water and on these was built a mass-concrete wall. Though the weight of this wall was small in proportion to the total weight of the structure the specifications required that the crib should be allowed ample time to settle and that it should be levelled up with additional timber on the top if necessary before the concrete blocks were placed,

but did not require that any filling be deposited before building the wall. No tie rods were used in this structure.

Similar construction was employed at Oswego, N.Y., in which type additional stiffness was supplied by vertical timbers in the corners of the pockets. The pockets in this crib were 10 feet by 7 feet 6 inches in area and the rear face of the crib was built in steps, as shown in Fig. 16. There were 350 feet more lumber per linear foot of wall in this design than in that of Buffalo and 153 pounds more steel fastenings, which made a very considerable difference in the cost.

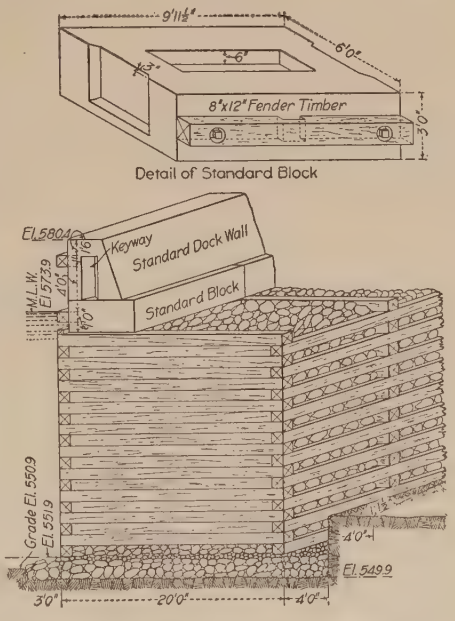

Fig. 15. Crib Wall, of Sawed Lumber with Upper Portion of Concrete, Barge Canal Terminal, Buffalo, N. Y.

The stiffness and stability of cribwork may also be increased by filling some or all of the pockets with concrete, as in the wall of the North German Lloyd Steamship Co., at their pier at Hoboken, N. J., shown in Fig. 17. The cribwork was founded on piles driven through mud to rock and cut off at 22 feet below mean low water. It was built of sawed lumber with pockets 10 feet square filled with 1: 2: 5: concrete deposited under water by means of a bottom opening bucket and was surmounted by a stone masonry wall with mass concrete backing. This method of construction permitted an examination of the concrete, which was found to be sound and strong. Riprap was used in front and in rear of the cribwork to aid in resisting the thrust

of the filling, and cobble was used to consolidate the mud and to give lateral support to the piles. Corner and diagonal braces were used in the pockets to prevent distortion of the cribwork while it was being filled.

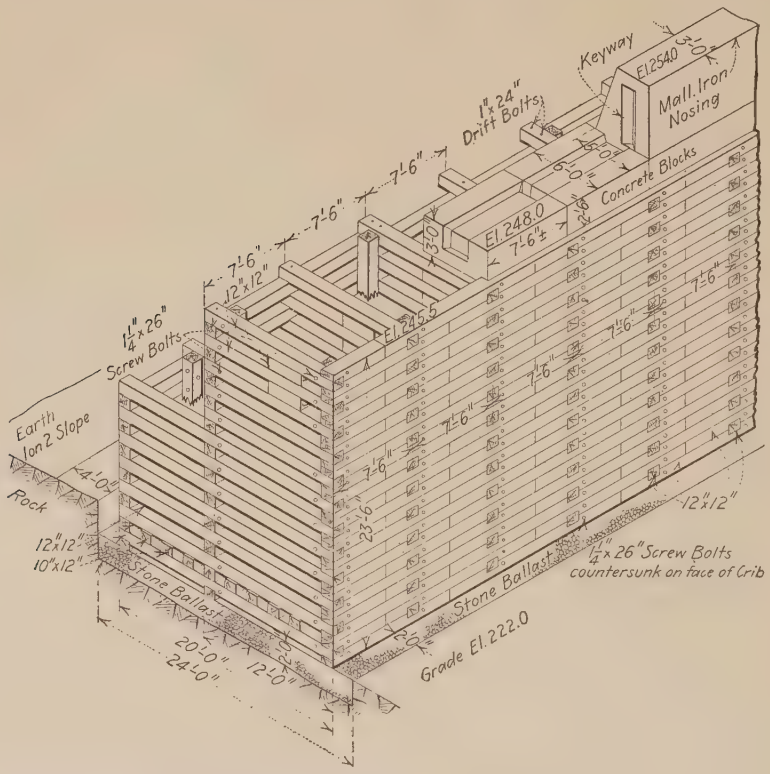

Fig. 16. Crib Wall of Sawed Lumber with Upper Portion of Concrete, Barge Canal Terminal, Oswego, N. Y.

At Depot Harbor, Ont., the upper portion of a timber crib wall which had decayed was replaced in 1904 with new cribwork made of 12-inch square reinforced concrete logs as shown in Fig. 18. Table II on page 18 gives a ready means of estimating the relative economy of this method. The lower portion was built of round timber in the usual manner. The main concrete logs were 20 feet long and had $2\frac{1}{2}$-inch holes moulded in them at varying distances

apart, arranged to allow dowels or bolts passing from top to bottom of the face of the concrete crib to be inserted after the holes were filled with grout. In the rear the cribwork was stepped and the members fastened together with screw bolts. The cross ties were dovetailed into facing pieces and short pieces inserted to fill the spaces between their ends and make the facing solid. Concrete mixed in the proportion of 1: 2: 3 was used with $1\frac{1}{2}$-inch

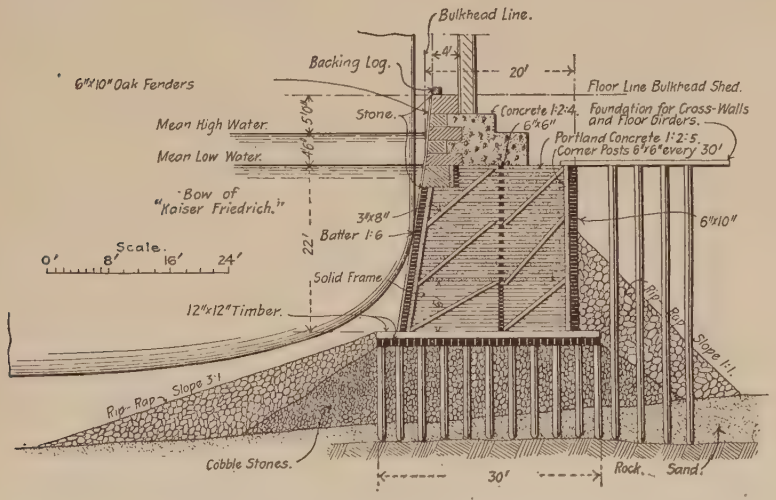

Fig. 17. Crib Wall with Concrete Filling, North German Lloyd Co., Hoboken, N. J.

stone. A similar construction was specified for a 2400-foot break-water at Port Colburne.

Quarried Stone Walls. — In some places where quarried stone is cheap and the bottom hard and reliable this material may be used economically. It requires, however, careful levelling of the bottom with gravel or broken stone, expensive floating derricks of large capacity, and a considerable amount of work by divers.

A good example of a quarried stone wall built in Boston in 1910 is shown in Fig. 19. The pier which this wall surrounds is situated near large granite quarries located on the shore and suitable floating derricks were available.

The fact that the climate in Boston is severe and the tidal range is unusually large and that there had been many failures of concrete between high and low water may have had considerable influence in the choice of granite instead of concrete.

Concrete Block Walls. — Where concrete blocks are cheaper than quarried stone they may be used in a similar

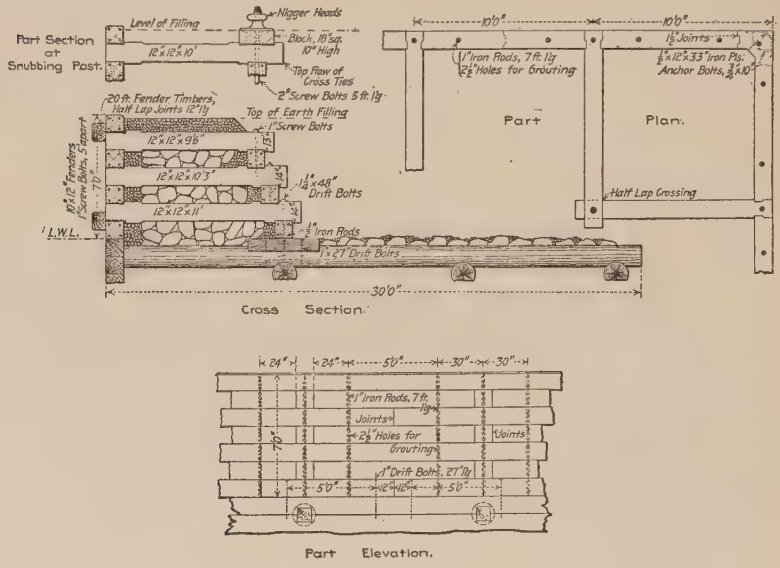

Fig. 18. Crib Wall of Reinforced Concrete, Depot Harbor, Ont.

manner, as shown in Fig. 20. The large concrete blocks in this wall are of 70 tons, weight. The portion above low-water level was made of granite with concrete backing, as concrete was not considered sufficiently durable for a work of such a monumental character. Riprap was placed behind the wall to reduce the thrust of the filling and the rock bottom was levelled off with concrete in bags placed by divers, with a top coat of gravel concrete worked smooth by means of heavy straight edges. The water at some places where this wall was built is 36 feet deep at mean low tide.

A wall of blocks on piles is shown in Fig. 21. This type of wall is used in New York, where the piles can reach rock and where the bottom is sufficiently firm to prevent any horizontal movement of the piles. The bottom is dredged to a depth of 20 feet and the piles cut off at 15 feet. Any soft material is pumped or washed out and the space between them filled with cobble to the top of the piles. A concrete mattress as described on page 90 is placed on the heads of the piles just before the base blocks

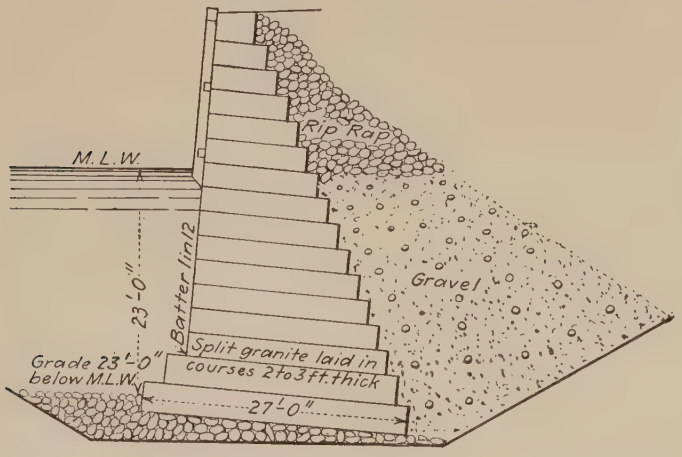

Fig. 19. Granite Masonry Wall, Commonwealth Pier No. 6, Boston, Mass.

are set. Riprap is placed behind the wall to diminish the earth-thrust and in front of it to aid in resisting the horizontal pressure.

A very heavy wall of hollow concrete blocks filled with concrete and stone is now under construction at Halifax, N. S. This wall forms the retaining structure for a marginal landing wharf for the largest ocean steamships, also for a solid-filled pier, aggregating some 6500 feet in length. It is planned to build, eventually, five more piers of similar construction. The depth of water at the face of the wall, as designed, varies from 45 feet at low tide for the major

portion to 30 feet for a small part where the rock excavation for greater depths would be excessive.

Among the conditions under which this wall is being built are the presence of rock over the entire site at depths

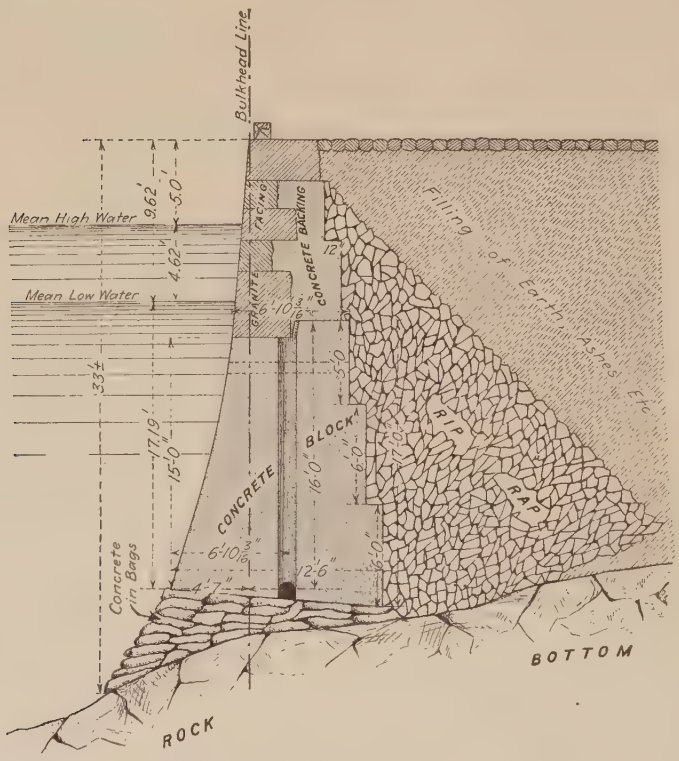

Fig. 20. Concrete Block Wall on Rock, West 52nd St., New York, N. Y.

of from 15 to over 60 feet, a location exposed to heavy swells, a large amount of waste rock and earth available for filling, and the impossibility of driving piles on account of the rock bottom. Speed and the carrying on of the work during the winter were among the requirements.

Five general types of structure were considered in adopting the chosen design: (1) concrete block walls with mass-

concrete filling; (2) concrete caissons, with concrete bottoms, floated into place; (3) a solid block wall; (4) a concrete platform on concrete columns; (5) a wall of cellular concrete blocks.

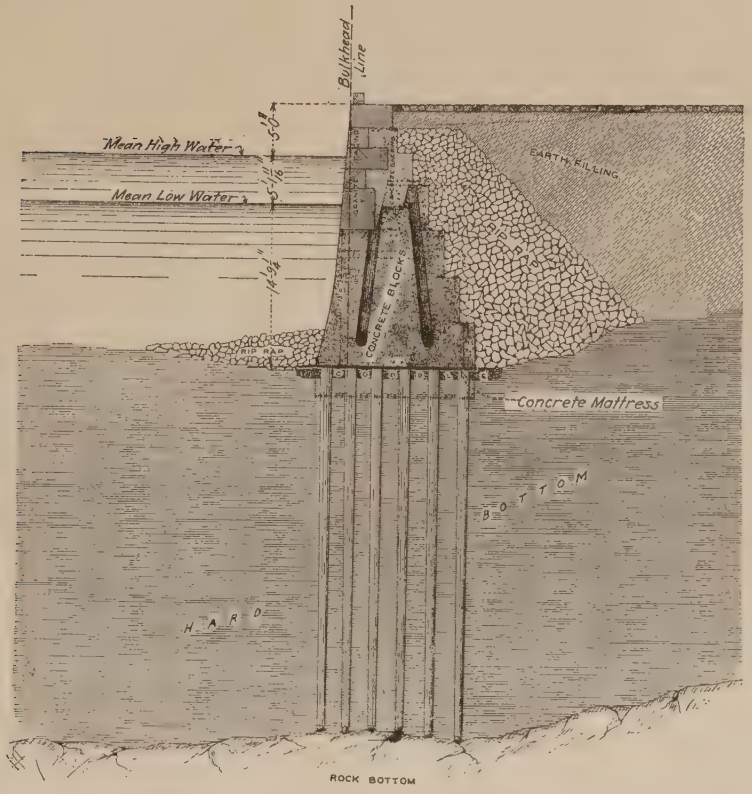

Fig. 21. Concrete Block Wall on Piles East 102nd St., New York, N. Y.

The first plan involved difficulties in preparing the bottom and required expensive temporary staging; the second required expensive plant for launching, winter work would have been impossible, and it would have been difficult to make a good bond between the caissons and the bottom; the third plan had the same objections as to the bottom and plant; the fourth plan involved risk of injury during

construction and would have cost about as much as the fifth, which was cheaper than the first three.

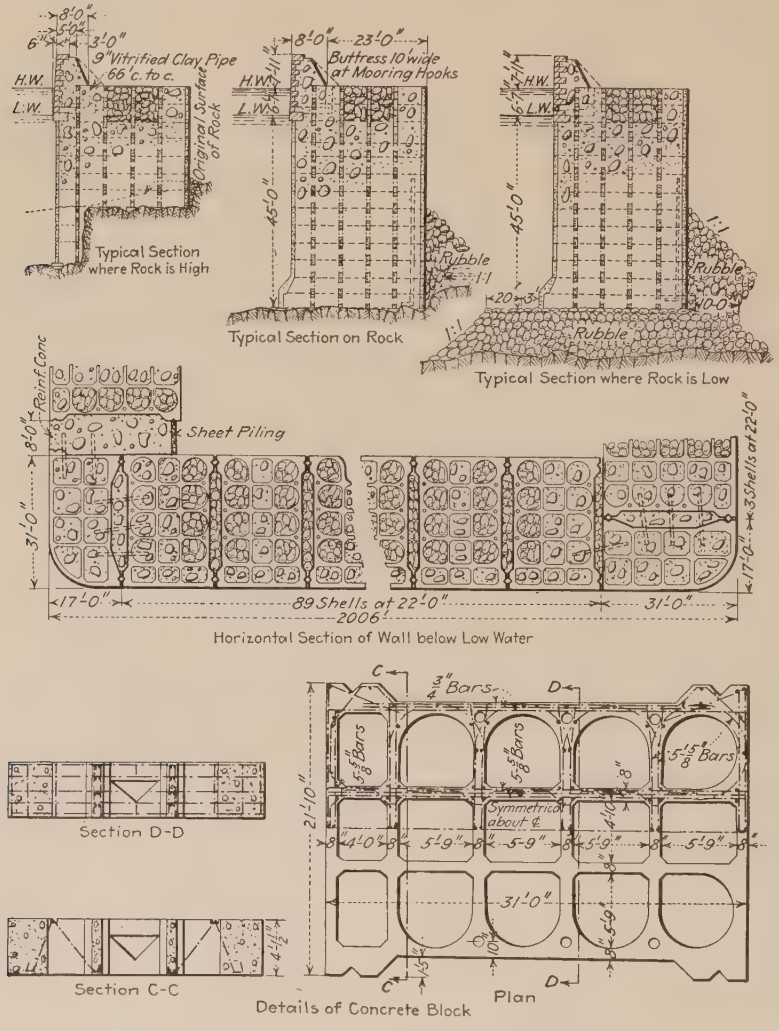

Fig. 22. Wall of Hollow Concrete Blocks, Halifax, N. S.

The adopted design consists of stacks of cellular concrete blocks, 31 feet long, 22 feet wide, and 4 feet high, weighing about 60 tons, reinforced against handling stresses and

those existing when the filling is completed. These blocks are placed on the prepared foundation by a very large locomotive crane operating on tracks placed on the stacks of blocks already in place. They are kept in vertical alignment by reinforced concrete guides placed in triangular grooves formed in the sides of the blocks.

After a stack of blocks is in place all the pockets in the lower layer are filled with concrete and those in the second layer are filled half full. Circular holes extending through all the blocks of a tier are then filled with grout, thus filling and bonding the horizontal joints between the blocks. Old rails are placed in some of the grout holes to strengthen the bond between the layers of blocks. The front row and the middle transverse rows of pockets in each block are also filled to the top with concrete, making a solid concrete buttress in each tier. The other pockets are filled with rock and sand.

The two upper layers of blocks were made narrower than those below and a mass-concrete wall was carried up behind a granite facing from low water to the grade of the filling. Granite was used, as previous efforts to obtain concrete proof against destruction by frost and sea water between high and low tide in the extreme climate of this locality had been unsuccessful.

A bank of riprap was placed in the rear of the wall to reduce the pressure of the filling.

The bottom is prepared in several ways, according to the height of the rock. Where the latter is above elevation 45 feet below low water, the rock is blasted off and concrete pedestals laid under the corners of the blocks by means of a large diving bell which permits accurate work and thorough inspection. Where the rock lies far below the 45-foot depth a rubble mound is placed and allowed to settle for a year before the concrete pedestals are laid on it, as described above. Where the rock is only a few feet below the bottom of the blocks a mass concrete foundation is laid under water in a steel-sheet pile cofferdam. Under these

conditions the pedestals are also laid and levelled off under water.

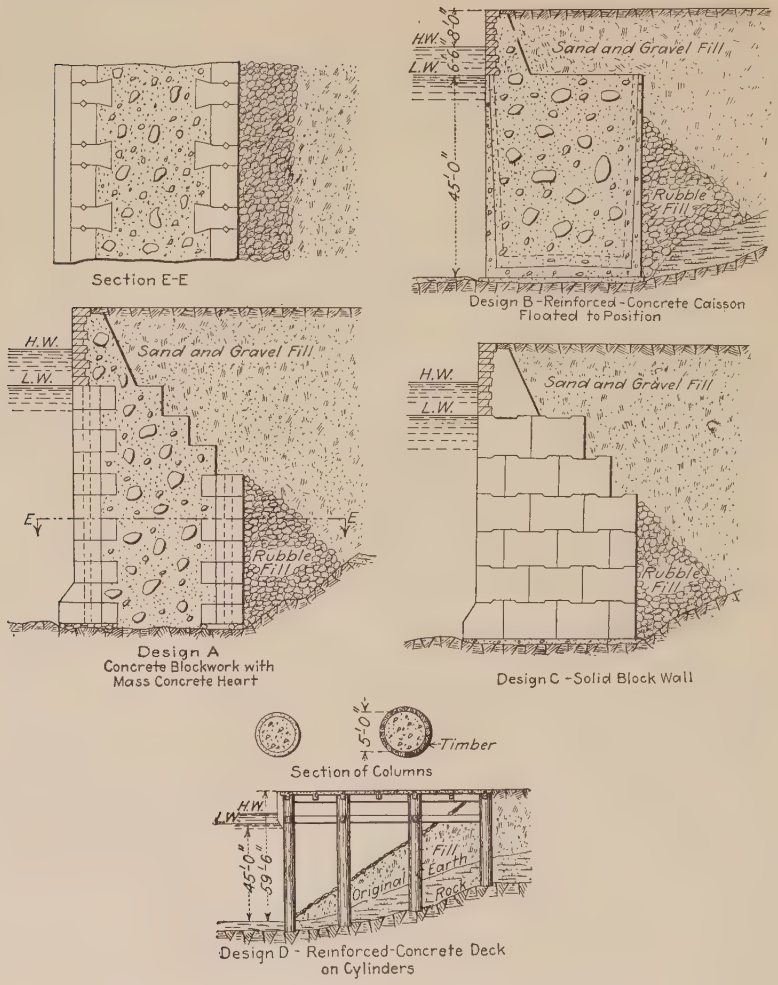

Fig. 23. Rejected Designs for Wharf Wall, Halifax, N. S.

The advantages of the chosen design are that it permits the moulding of the blocks in the air, the rejection of all imperfect concrete, rapid construction, requires comparatively small plant, no temporary staging, and permits the depositing of concrete under water in a permanent form

under the best conditions for such work. The concrete in the lower pockets makes a strong, uniform bearing for the wall on the foundation and gives a strong bond between the two. The stacks of blocks not being connected, any vertical settlement which may take place during construction as well as expansion and contraction both vertically and horizontally is free to take place.

A considerable portion of the wall has been completed and the methods described are reported to give most satisfactory results in rapidity of construction and accuracy of alignment and levelling of the stacks of blocks.

Mass-concrete Walls. — Walls of mass concrete may be built in cofferdams where located in the water, and, in places where the slips or basins are to be excavated in the land and the water can be excluded, they may be built in sheeted excavations. Such walls may also be built in submerged forms, the concrete being deposited in the water by means of a tremie. The latter method has had many failures caused by the washing out of the cement from the concrete, and those that have been successful, for the portion under water, have in numerous cases not resisted the action of frost between high and low tide.

A wall of this type constructed in a cofferdam is shown in Fig. 24. The depth of water was 25 feet at mean low tide. The cofferdam was somewhat difficult to maintain and the difference in cost between that and the block walls was so small that the block type was built in subsequent sections under similar conditions.

The New York State Barge Canal affords many examples of mass-concrete walls built in the dry or in cofferdams. Fig. 25 shows the general form adopted for retaining walls for the canal banks, where no provision is made for surcharge of cargo.

A wall 44 feet in height and 2005 feet long was built of mass concrete in a sheeted and braced trench at Oakland, California, as illustrated in Fig. 26. The facing is of richer concrete than the main portion of the wall in order

to make this portion more impervious and so more resistant to the action of sea water. The fender piles are stepped in sockets cast in the lower portion of the wall and fastened by bolts extending through the wall in a 2-inch pipe in order

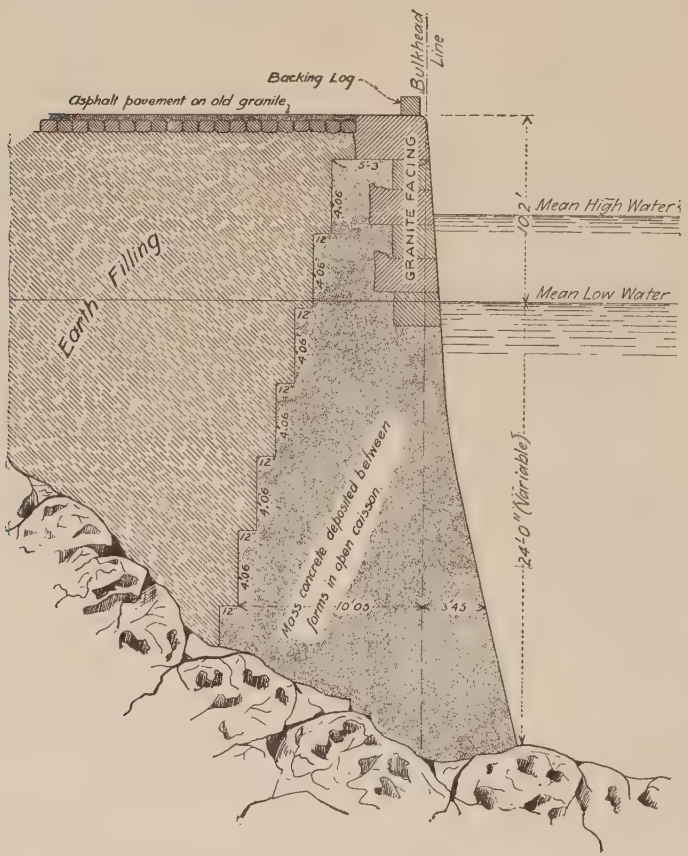

Fig. 24. Mass Concrete Wall, East 116th St., New York, N. Y.

to facilitate renewal. The earth inside the trench was removed by the hydraulic method, water being pumped from the harbor to a monitor, the earth, as it was loosened, sluiced to a sump and pumped out to the deeper portions of the harbor. The earth outside the wall was dredged out after the wall was completed.

A good example of mass-concrete walls supported on piles, 29 feet high and extending 17 feet below mean low water

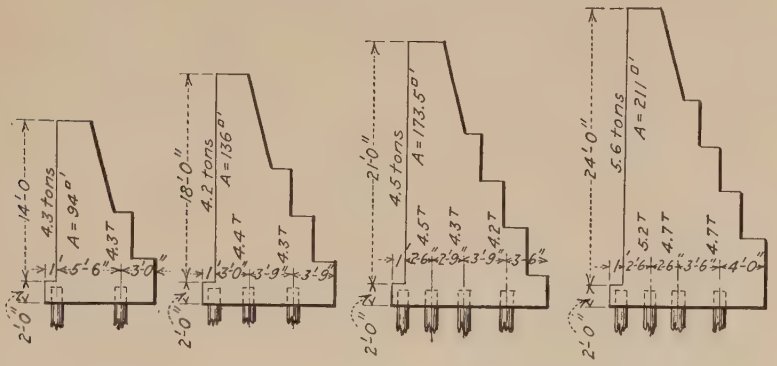

Fig. 25. Mass Concrete Walls, New York State Barge Canal.

with a platform on piles as shown in Fig. 27 was recently constructed in San Diego, Cal. The bottom was excavated on a slope under the platform and a depth of 20 feet obtained at the face of the wharf, which was 25 feet wide. Riprap was used to prevent erosion of the earth slope and to assist somewhat in taking the thrust of the filling.

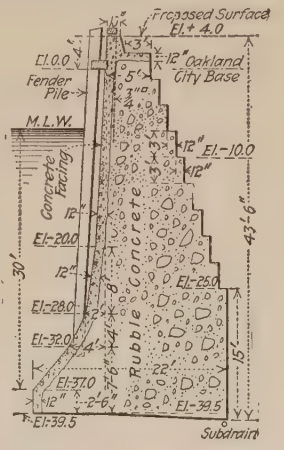

Fig. 26. Mass Concrete Wall, Oakland, Cal.

Floating Caissons. — Retaining walls built of caissons or boxes of wood, steel, or reinforced concrete, floated into place and then filled with various materials, have been built in some places.

Two such walls in Denmark have interesting and unique features which might be used in this country. One 3300 feet long built in Copenhagen for a harbor basin is shown in Fig. 28. There are twenty-two reinforced concrete caissons made of a 1: 2: 3 mixture, each 162 feet long, 32 feet high, and 16 feet wide, which were built in a temporary

dry-dock large enough to contain three at one time. The front walls are $10\frac{1}{2}$ inches thick, those at the ends of the caissons $13\frac{1}{2}$ inches and the partitions only $7\frac{7}{8}$ inches. The depth of water at the front of the wall is 31 feet. The most interesting feature is the granite-faced wall extending from just above the water level to the top, which projects in front of the face of the caissons and protects them from the impact of vessels. The portion of the wall subject to freezing is protected by a thin facing of granite. In a similar wall built several years previously at Nörre Sundby

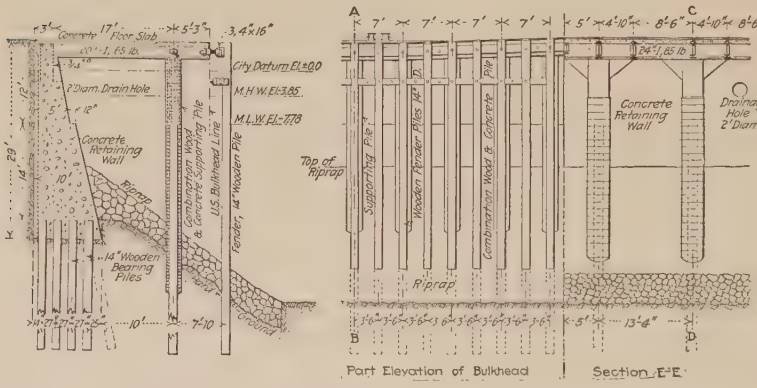

Fig. 27. Mass Concrete Wall, with Concrete Pile Platform, San Diego, Cal.

in water $24\frac{1}{2}$ feet deep the exterior walls were notable for their extreme thinness, being only 5.1 inches thick at the bottom and 3.5 inches at the top. The caissons in this case were built on shore and launched by means of slipways. In both walls the caissons were filled with sand.

Another example in which the walls are much thicker is that of the wharf walls of the new Welland Canal shown in Fig. 29. The caissons, which were 110 feet long, 38 feet wide, and 34 feet high, were open at the bottom but were fitted with temporary wooden bottoms to keep them afloat while they were towed to the site and sunk. They were built in floating pontoons which were arranged so that they could be taken apart and removed as soon as the

caissons would float. As the stresses in the walls while afloat were much greater than after the caissons were in

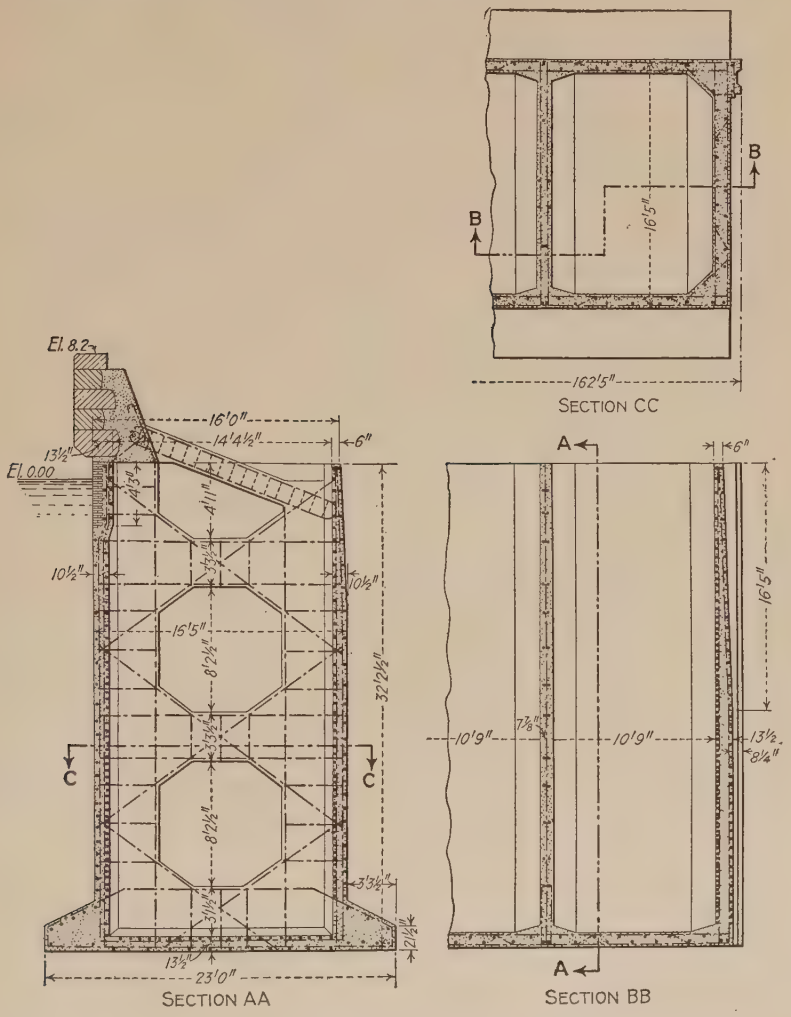

Fig. 28. Wall of Concrete Caissons, Copenhagen, Denmark.

place and filled with stone, the pockets were braced during transportation with timber, which, with the wooden bottoms, was removed as soon as the caissons were in place and used over and over. The caissons rested on windrows of stone

placed on the dredged bottom under the longitudinal walls, and, after the temporary wooden bottom and bracing were removed, they were filled with dredged material. The outer edge of the row of caissons was surmounted by a mass-concrete wall built after settlement ceased. Fifty-three such cribs were built, and their great number made

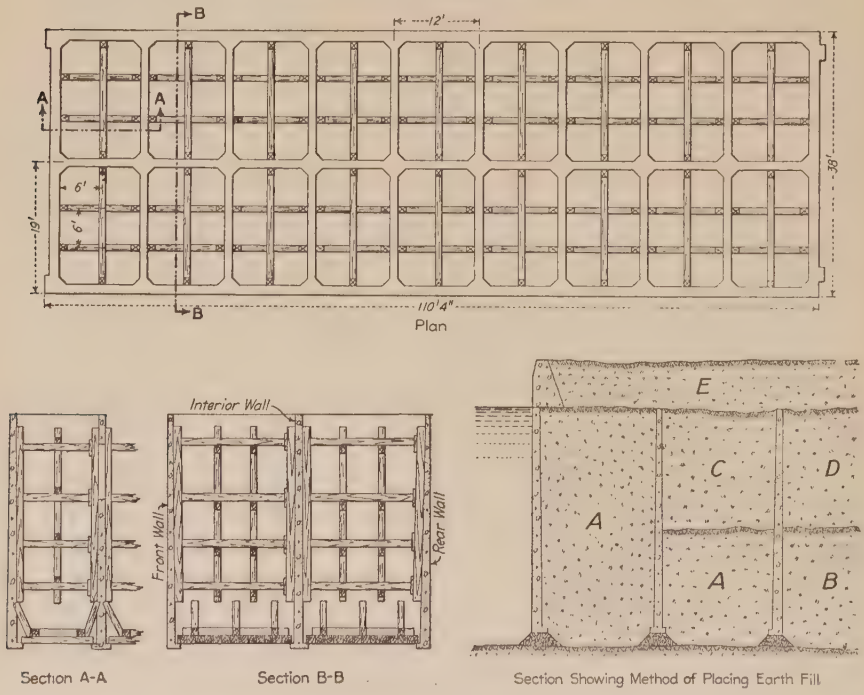

Fig. 29. Wall of Concrete Caissons, Welland Canal, Ont.

this form of construction economical. The most notable feature of this wall was the saving in concrete due to the ingenious and novel use of temporary wooden bottoms and bracing to resist the stresses while the caissons were being floated into position. It is stated that certain features of this design have been patented.

A wall at Victoria, B. C., of reinforced concrete caissons or cribs, as they are locally designated, in which the bottoms of the caissons were of concrete and the walls sufficiently

strong to withstand the water pressure when the caissons were afloat, is shown in Fig. 30. In this case the cribs were 85 feet long, 35 feet wide, and 39 feet high and the outer walls were 20 inches thick. They were braced with two longitudinal walls and with transverse walls every 10 feet. Additional deep beams between the transverse walls distribute the pressure of the mass-concrete wall, 12 feet high and 16 feet above the water, which is built on top of the cais-

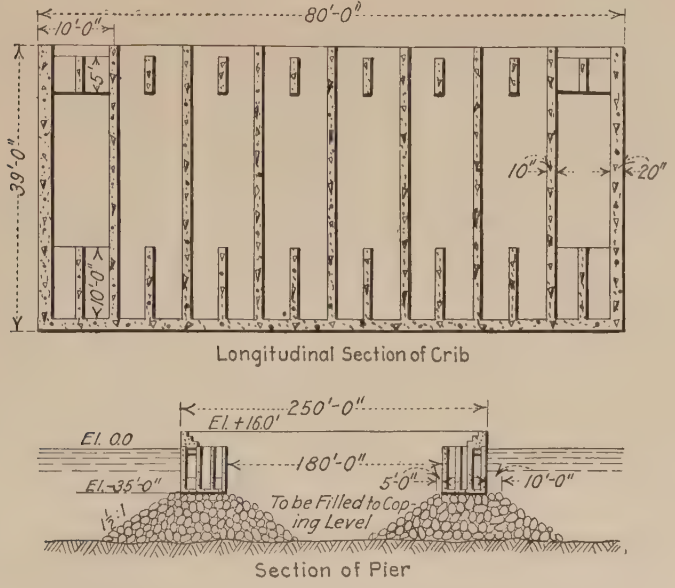

Fig. 30. Wall of Concrete Caissons, Victoria, B. C.

sons. The cribs drew 28 feet of water when launched. The first ones were built in a floating dry dock, which was wrecked by premature flooding, and the later ones were constructed on a marine railway.

These cribs, fifty-four in number, were used for enclosing solid-filled piers 800 to 1000 feet long and 250 feet wide in water having a maximum depth of 65 feet, and a novel feature in their construction was the preparation of the stone mound foundation on which the caissons rest. Large stone was deposited by deck scows, which slid their load

overboard when water was admitted to longitudinal compartments located along the sides of the hulls, to an elevation of 36 feet below the water surface. Any rock projecting above this level was removed with a clamshell or orange-peel dredge bucket. The mound was then levelled up with gravel to elevation –35 and the gravel smoothed off by means of a plough suspended from a pile trestle driven into the riprap. The plough was a heavily braced timber structure, weighted with stone and having a pointed end shod with iron.

It was hung by rods from beams arranged to move along the top of the trestle-work and when adjusted at the proper height it was hauled along the trestle, ploughing off any gravel above the required elevation.

A comparison of the two foregoing cases is interesting.

Reinforced concrete caissons for a breakwater at Algoma, Wis., 24 feet long, 15 feet wide, and 12 feet, 4 inches high were built by day labor for $17.66 a cubic yard for the concrete. The wall of caissons with pile foundation, concrete filling, and superstructure cost $75.67 per linear foot.

Relieving Platform Walls

Relieving platform walls may be defined as those in which a platform on piles, in combination with banks of riprap, masonry walls, or lines of sheet piling forms a part of the structure and relieves the wall itself of the pressure of the live load and of any filling on the top of the platform, and of a part of the horizontal pressure of the filling beneath. The platform may be located at or near the level of low water or may form the deck of the wharf.

The main object of the platform in retaining structures is to diminish the cost by the elimination or reduction of the thrust which is the necessary accompaniment of any wall which has a vertical facing on the front edge for the whole depth required by shipping. This object is attained in two ways: first by building the platform over a sloping bank, either natural or artificial, having its face at a safe

angle of repose, and second, by placing the platform behind a wall of masonry or sheet piling.

If the first method is used the platform may be placed over a bank of riprap which retains the filling, as in Fig. 32 or, if the wall be built inside the natural shore line, it may be placed over a dredged slope, protected against erosion by a revetment of stone, as in Fig. 37. In some cases such a platform has been built over an existing sloping shore without any dredging or revetment. A low wall of masonry or sheet piling may be placed at the rear of the platform in order to reduce the width of the latter and to provide a tight bulkhead to retain the filling at a point where the riprap is thin.

This type of wall is particularly suitable for tidal waters where the range of tide is not too great, but platform walls of the first type are open to the same objections that apply to any wooden structure in waters where marine borers are met with.

An example of a platform wall built at some distance from the shore is that built at Gowanus Bay, Brooklyn, N. Y., and shown in Fig. 31. A hard sand, clay, and gravel bottom was found at 17 feet below low water, overlaid with mud 12 or 15 feet deep. Marine borers were absent and there was no objection to the use of untreated piles below half tide. A trench was excavated to a depth of 17 feet, for a distance of 25 feet in rear of the face of the wall, with a natural slope on the inshore side. The slips between the piers, which are to be built in front of this wall, were dredged to 35 feet depth and a berm 50 feet wide at the bottom was left in front of the wall opposite the slips. The piles were then driven and capped and the riprap deposited. After some time had elapsed to allow for settlement the riprap was brought up to the under side of the platform, the deck laid, and the concrete wall built. The area back of the wall was then filled with selected sand and gravel pumped from the slips. Some difficulty was caused by the filling washing through the riprap at its

junction with the platform, where the thickness of riprap, through which the filling passed, was a minimum. This could have been prevented by careful grading of the riprap to make it sufficiently tight to hold the filling, by depositing a bed of selected dry filling over the riprap, or by placing a vertical sheeting at the rear edge of the platform.

It is important to make the dredged trench of sufficient

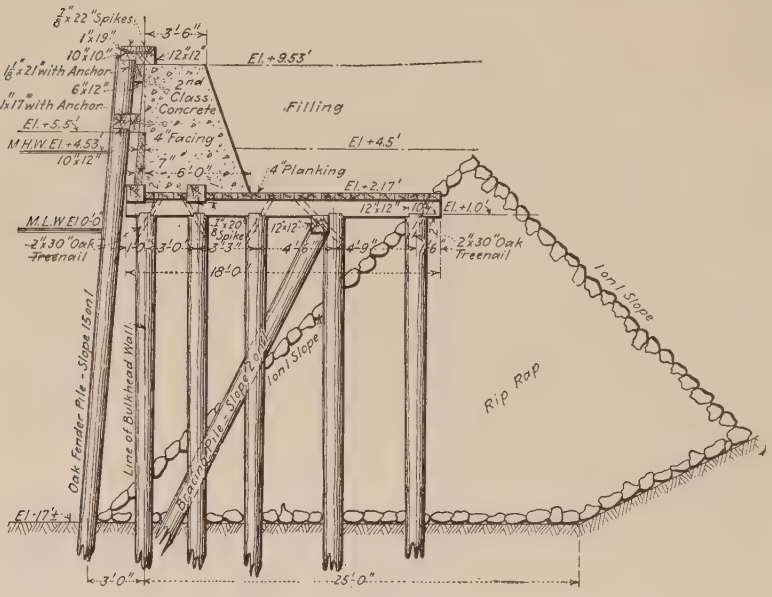

Fig. 31. Platform Wall, Gowanus Bay, Brooklyn, N. Y.

width, in the rear of such a wall, to prevent the riprap from sliding and pushing the piles out of plumb. Where such a wall encloses a large tidal area to be filled by pumping, special attention must be paid to the management of the filling and to the openings for controlling the effluent of the pumps and the flow of the tide through the wall, in order to prevent the washing of the dredged material through the riprap.

This wall was designed for a live load of 500 pounds per square foot and required piles to be placed 4 feet longi-

tudinally and 4 feet transversely on the average to give a loading not exceeding 12 short tons on the piles.

The concrete was made with gravel in the proportion of 1: $2\frac{1}{2}$: 5 except a facing of 1: $1\frac{1}{2}$ mortar 6 inches thick extending up to above high water. It is expected that the dense, rich face will withstand the action of frost in the

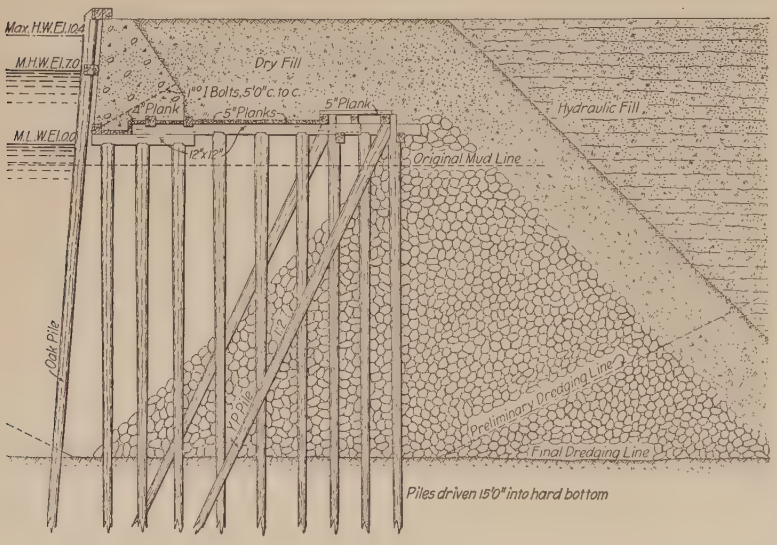

Fig. 32. Platform Wall, Hunts Point, New York, N. Y.

salt water. No concrete was allowed to be deposited when water was in the forms.

Another example is that of a very long wall at Hunts Point, New York, illustrated in Fig. 32. Here the desired depth was 30 feet. Sand mixed with gravel, or rock, was found at depths varying from 25 to 65 feet, overlaid with mud extending up to from 1 to 4 feet below low water. A trench was dredged to 30 or 35 feet below low water or to the hard bottom, where it existed at lesser depths. The piles were then driven and capped. Railroad tracks were laid on a temporary trestle placed on the caps, and stone from the subway excavation then in progress

near by was brought in dump cars and deposited between the piles. The greatest care was taken in depositing this stone to prevent the displacement of the piles. A second deposit of stone in the rear of the piling was made from scows, and the final deposit was then sealed with ashes and street sweepings and the area behind the wall filled with mud pumped from in front. The necessity for removing the mud before depositing the stone was shown by the fact that an attempt to make a rock fill for a dike on the

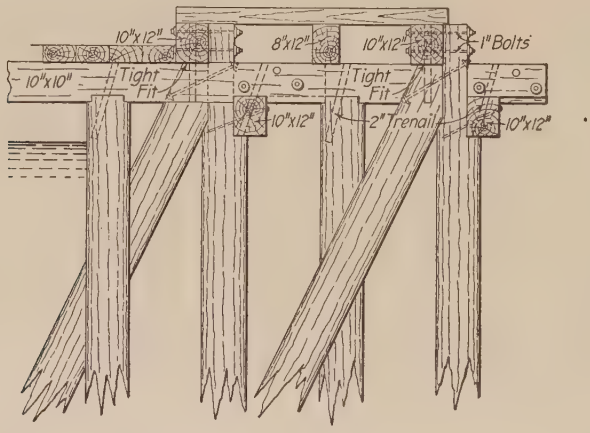

Fig. 33. Details of Fig. 32.

side of the filled area, by dumping the stone from a trestle without removing the mud, resulted in the pushing out of the piles and the destruction of the trestle.

The tidal area enclosed by the wall and banks of stone partially sealed with fine material as described above was so large that the size of flood gates to be of any use would have been prohibitive and the final closing of the retaining structures was accomplished with considerable difficulty.

A feature of the filling was its solidification by mixing ashes and street sweepings with the soft mud. The mud thus consolidated had sufficient bearing power to support tracks for transporting and distributing the street refuse.

The platform is notable for the careful design of the

connection between the platform and the bracing piles, which is shown in the illustration, and for the front portion being lower than that in the rear of the concrete wall. This was for the sake of the appearance at low tide, as it was

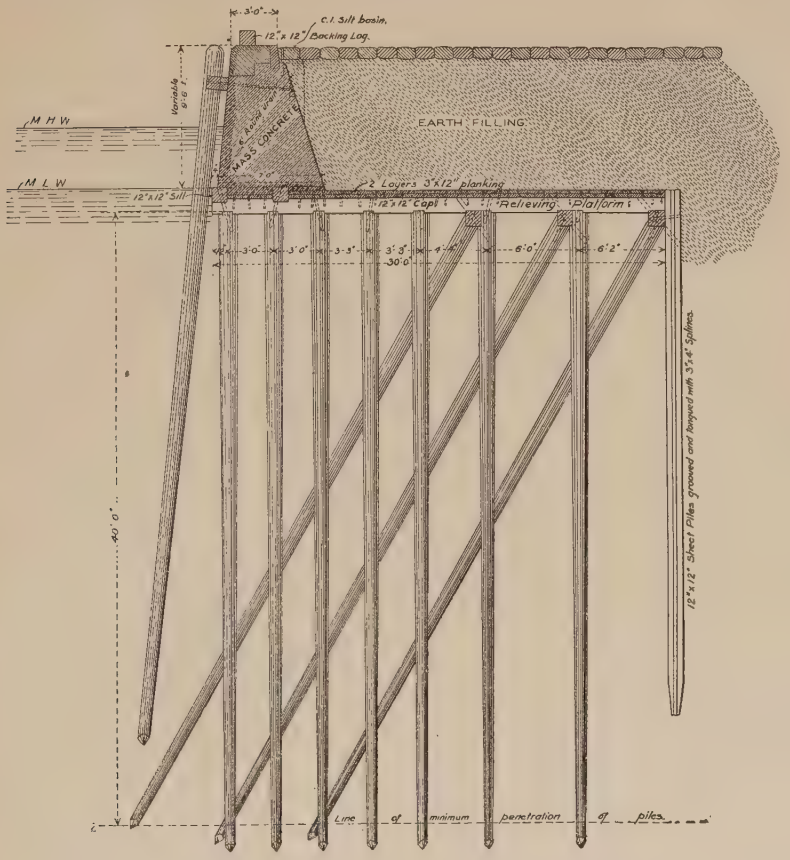

Fig. 34. Platform Wall, Wallabout Basin, Brooklyn, N. Y.

considered desirable to have the concrete extend down to as near low water as possible.

Where rock was found at such depths that piles could not be driven in the natural bottom, the mud was dredged, a layer of stone deposited, and the piles driven through the stone.

Heavy wooden sheet piling supported by bracing piles is the principal feature of the wall at Wallabout Bay, New York City, shown in Fig. 34. This wall has no anchors or tie rods. It was built inside the shore line, and the channel outside it was excavated after it was built.

A wall at Los Angeles, Cal., is illustrated in Fig. 35. In this case riprap both behind and in front of a line of sheet

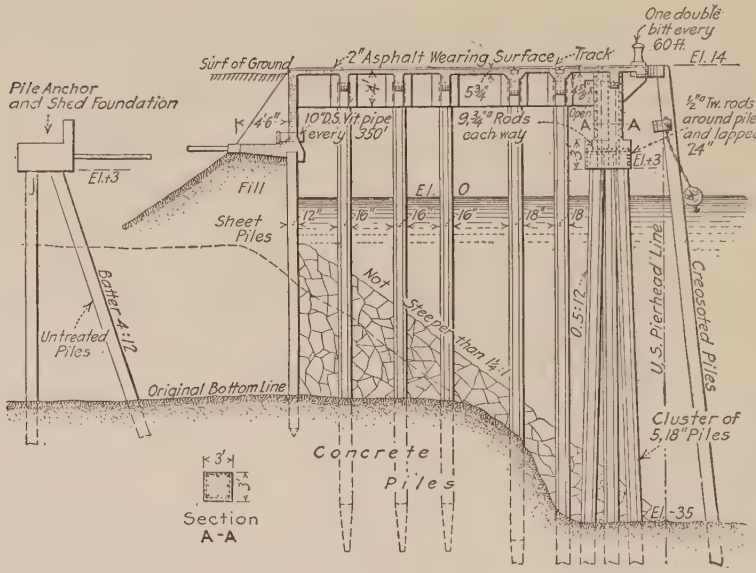

Fig. 35. Reinforced Concrete Platform Wall with Concrete Sheet Piles, Los Angeles, Cal.

piling takes a considerable portion of the earth pressure. All of the structure except the anchor piles is of reinforced concrete and none of the structure is destructible by fire, decay, or marine borers except the fendering. The fender piles are creosoted.

A design for a wall to be built inside the existing shore line is shown in Fig. 36. In this case the width of the platform was decreased to a minimum by using riprap to retain the filling, and the amount of riprap required was comparatively small, as it was possible to dredge the bank

on a slope. Care should be exercised in such a wall to prevent the riprap pushing out the piles. It is better to deposit some or all of the riprap before driving the piles.

A wall at Providence, R. I., in which sheet piling retains the filling and riprap is used principally to prevent erosion

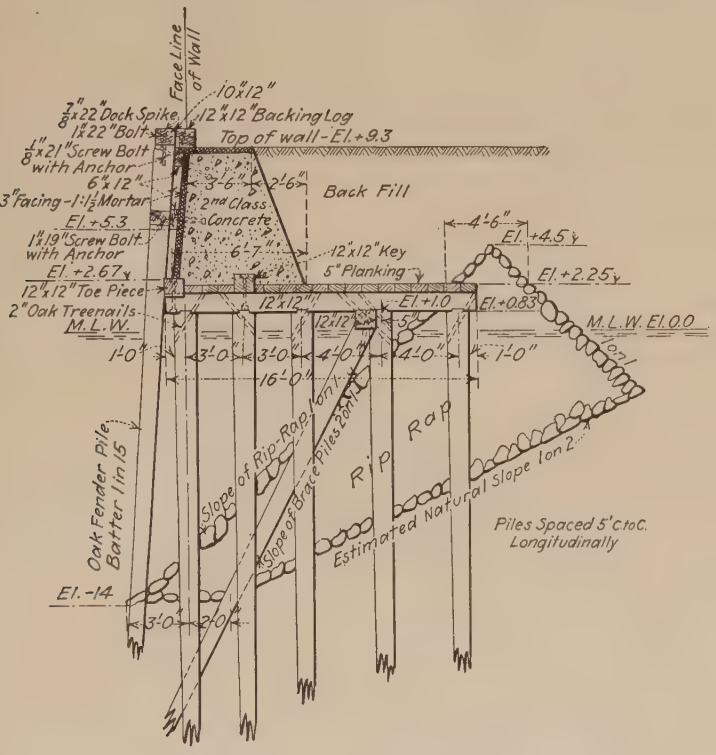

Fig. 36. Design for a Platform Wall inside the Shore Line.

is shown in Fig. 37. This wall provided 30 feet of water at low tide with a platform 30 feet wide. All of the piles and lumber in this wall were creosoted except the fender piles, the bearing piles having 16 pounds, and the lumber 14 pounds of oil per cubic foot. The masonry part of the wall was of granite ashlar backed with concrete, as the climate is severe on concrete exposed to freezing. The

caps were fastened to the piles by wooden dowels or tree-nails and all metal fastenings were of galvanized refined iron.

Bracing piles in such walls are not absolutely necessary, as the piles, stiffened and supported by the riprap, may be sufficient to take the thrust of the portion of the filling above the platform, as shown in Fig. 38 at Whale Creek,

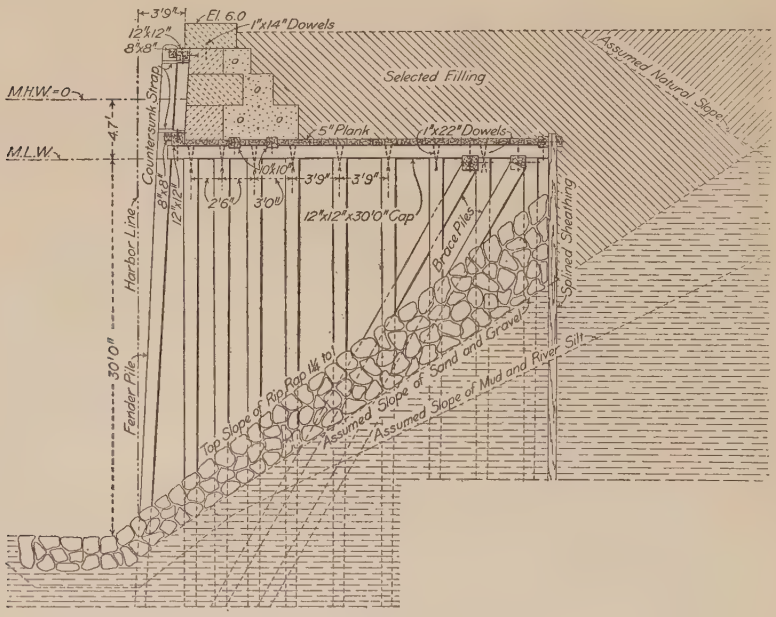

Fig. 37. Platform Wall, Providence, R. I.

New York, N. Y. This wall has been built several years and shows only a slight bulging, due to a soft spot in the bottom which was not dredged out. It has not, however, been subjected to any very heavy live load.

Earth-filled cribwork walls on the edge of the platform were formerly used instead of masonry. In some cases the cribwork was extended back of the platform in order to resist the outward thrust. Such construction is only temporary and failures have resulted from the rotting of the transverse

tie logs. The decrease in the cost of concrete and the increase of its durability in sea water, due to better mixing and proportioning, render it more economical than cribwork for this purpose under ordinary conditions.

A wall for 12 feet depth of water for a Barge Canal Terminal at Schenectady, N. Y., with a reinforced concrete platform, is shown in Fig. 39. It was built in a dry trench excavated within the shore line of the Mohawk River. Timber piles were substituted for the concrete piles shown

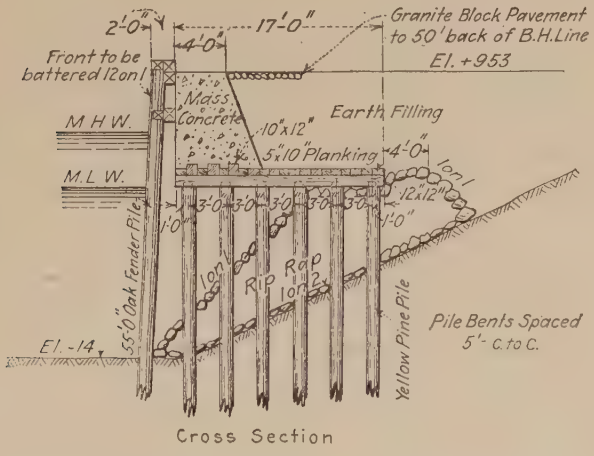

Fig. 38. Platform Wall, Whale Creek, Brooklyn, N. Y.

in the illustration. A similar wall, with a wooden platform, for another terminal at Whitehall, N. Y., is shown in Fig. 40. These designs were preferred for freight wharves, on account of their cheapness, to the standard type of gravity concrete retaining walls used all along the canal wherever a vertical face was required.

A novel type of platform wall over a sloping bank recently built at Savannah, Ga., is shown in Fig. 41. The main feature of this design, which was patented by William M. Torrance, is the sloping platform of reinforced concrete supported on piles. The dead load on the piles is less than

with the horizontal platform and superior economy is claimed for this type over that shown in Fig. 36.

A similar wall in which concrete piles support the sloping platform without the use of cross walls is illustrated in Fig. 42. This is a type used in Rio Janeiro.

The wall of the Bush Terminal in Brooklyn, N. Y., in

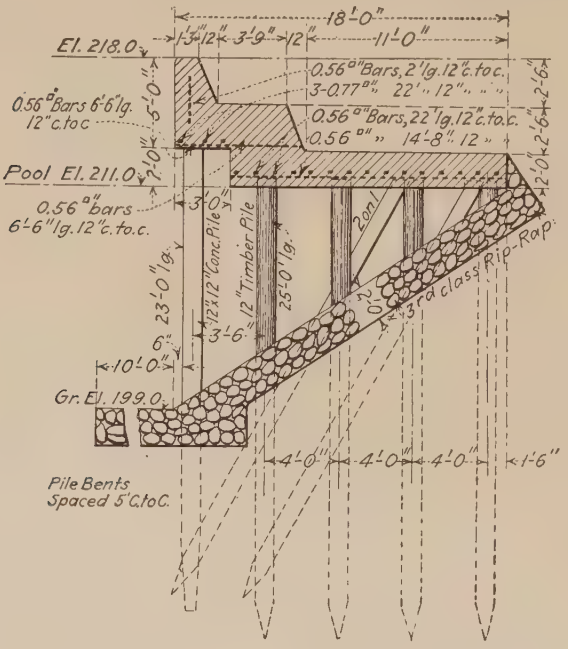

Fig. 39. Wall with Wooden Piles and Reinforced Concrete Platform, Barge Canal, Schnectady, N. Y.

which the platform takes only a small portion of the thrust, is shown in Fig. 43.[1] This type of wall was designed to retain the filling in large solid piers. The walls were all built far out from the shore on a hard sand and gravel bottom overlaid with mud. The sheet piling was first driven and then the slips between the piers dredged out, leaving a sloping bank of sand outside the sheet piling for

[1] "Wharves and Piers," E. P. Goodrich. Trans. Am. Soc. C. E., Vol. LIV, part I, p. 26.

the width of the platform. The sheet piling was tied with rods extending across the pier and a bank of riprap was placed to protect the slope against erosion and to aid in supporting the sheet piling. The wooden pile platform was then built with a wale against the top of the sheet piling. A

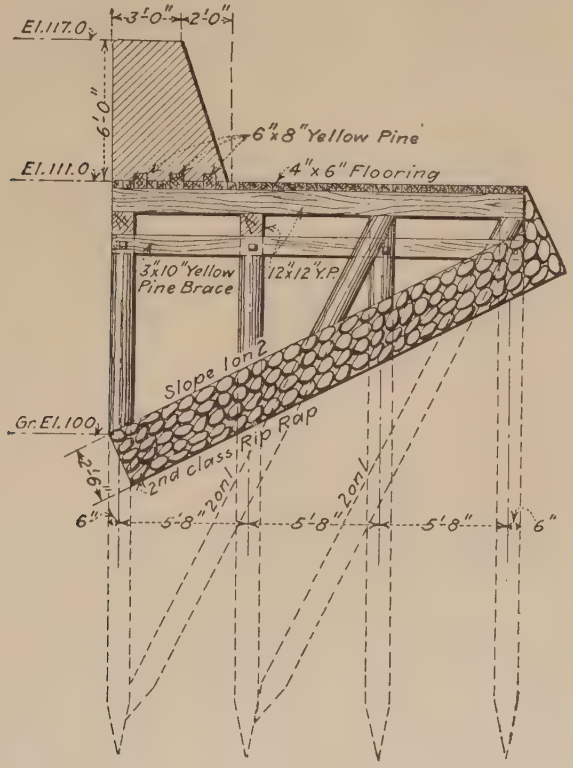

Fig. 40. Platform Wall, Barge Canal, Whitehall, N. Y.

portion of the wall was injured by a fire, and the sheet piling and side system of the piers had to be extensively repaired, on account of decay, after twelve or fifteen years' service. It is claimed, however, that the first cost of the construction was very low.

A similar wall was built in 1914, at Los Angeles, Cal., in which all the piles were creosoted.

One of the most remarkable sea or bulkhead walls is that constructed by the Department of Docks, in New York City, which in some places is built in mud 170 feet deep. It is of the relieving platform type, supported on piles, which do not extend through the mud to hard bottom, with a vertical facing of concrete blocks extending 17 feet below low water. This wall, as originally designed in 1876, is shown in Fig. 44. The mud was dredged for a width of about 85 feet to a depth of 30 feet, more or less, depend-

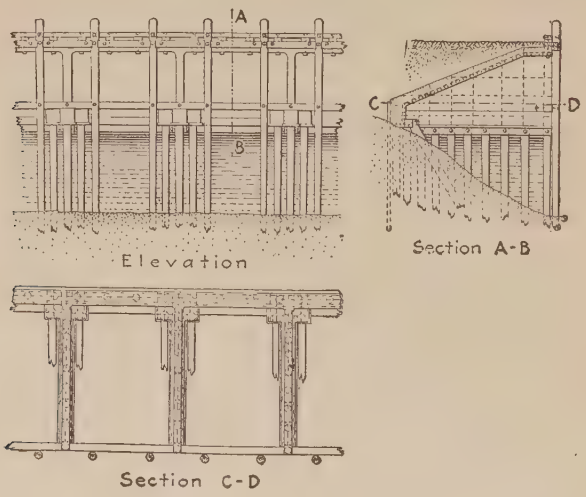

Fig. 41. Sloping Platform Wall, Savannah, Ga.

ing on the consistency. A layer of small, smooth cobble or gravel was then deposited to prevent the mud flowing into the trench, the piles driven, straightened, and stay-lathed. Guide logs were sunk between the longitudinal rows to aid the accurate alignment of the piles. Cobbles and riprap were deposited up to 18 feet below mean low water, cobbles being used between the piles, as they make a more compact filling than the angular riprap stone. A binding frame, in sections 24 feet long, was next slipped over the transverse rows of piles and sunk to the top of the bank of cobble by means of weights. Divers spiked it in

place and filled the spaces between the longitudinal timbers in front and rear and the piles adjacent to them with wedges. The object of this binding frame was to prevent the possible pushing out of the front row of piles from under the concrete blocks, which were only 7 feet wide on the bottom. The piles were then cut off with a circular saw mounted on a scow.

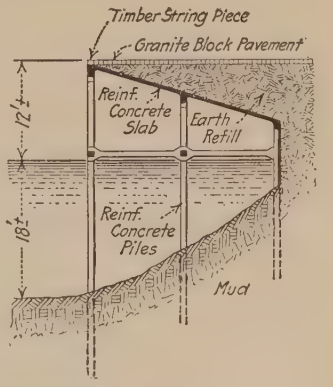

Fig. 42. Sloping Platform Wall, Rio Janeiro.

As it is impossible to space piles in actual practice with great accuracy, and as it was essential that the piles should all perform their full duty, it was necessary to ascertain accurately the location of the pile heads. For this purpose a wire screen, having ten meshes to the foot with a frame heavy enough to sink, was lowered by means of a derrick to the tops of the piles on which

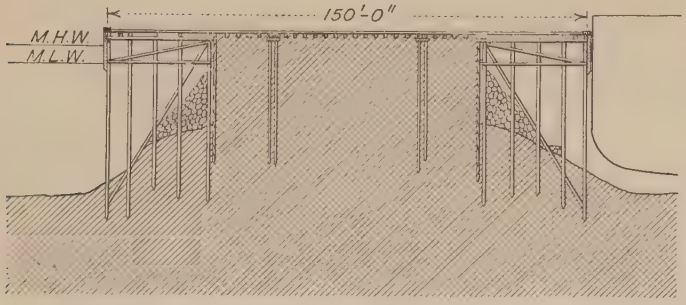

Fig. 43. Platform Walls, Bush Terminal, Brooklyn, N. Y.

the blocks were to rest. A diver then marked the position of each pile by means of snap hooks which he attached to the wires of the screen. The screen was then raised and the location of the pile heads plotted. If any piles were found which were outside the limits of the base of the

concrete blocks, or if they were too unevenly distributed, extra ones were driven.

It was impracticable to cut off all the piles at exactly the same level, and a novel means was adopted for insuring a uniform bearing of the block on all the piles. A weighted wooden frame larger than the base of the concrete blocks was covered with a network of small rope. On the network was placed a bag or mattress consisting of two sheets

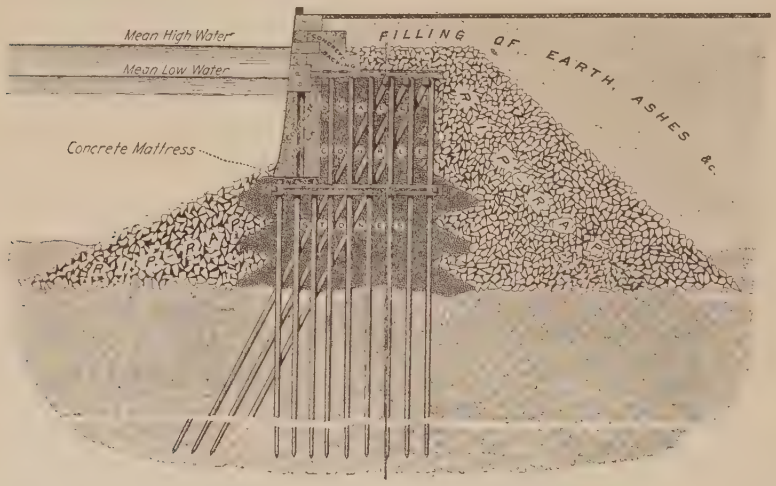

Fig. 44. Bulkhead Wall with Relieving Platform Type of 1876, Dept. of Docks, New York, N. Y.

of burlap filled with a layer of 1: 2 mortar, made with slow-setting cement, mixed to a stiff paste. When the concrete block was ready for setting, the mattress, filled with the freshly mixed mortar, was lowered to the tops of the piles and adjusted by a diver, who cut the rope netting around the edges of the frame. The frame was then raised and the concrete block immediately set on top of the mattress. Portions of the wall when removed, subsequently, showed the complete success of this device. The heads of the piles pushed into the soft mortar until the unit pressure was uniform and the mortar was found to be hard and sound.

The blocks were made of a comparatively dry mixture of 1: 2: 5 concrete, mixed by hand and thoroughly tamped and cured. They weighed about 70 tons, and were placed with a 100-ton capacity floating derrick owned by the department. The durability in sea water of these concrete

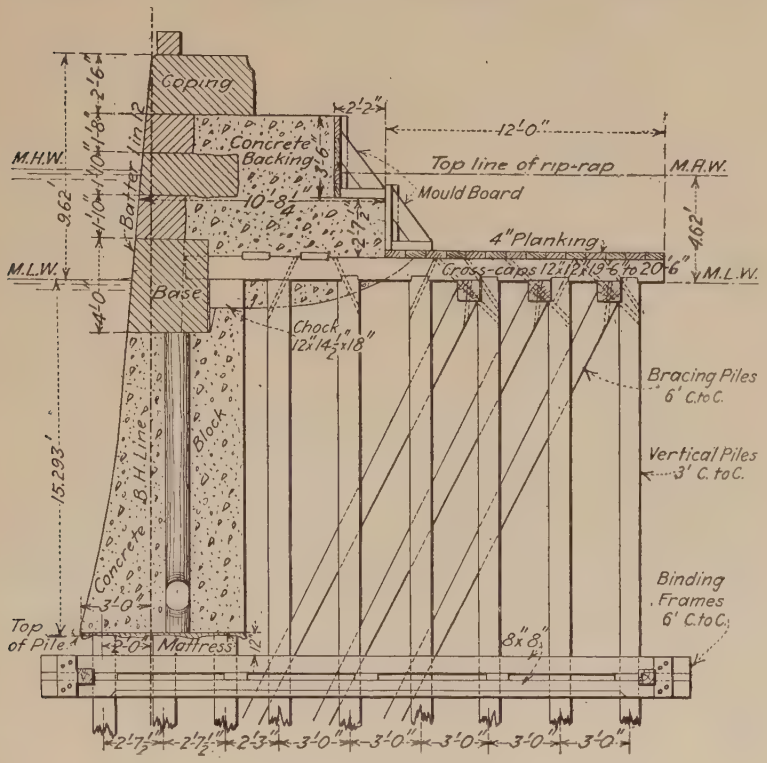

Fig. 45. Details of Fig. 44.

blocks, which do not extend above mean low tide and are not subject to the action of frost, has been referred to in a previous chapter. Above low water the masonry wall is of mass concrete faced with heavy, accurately jointed, granite ashlar.

Back of the masonry portion of the wall the spaces between the piles were filled with cobble, the platform laid, and the riprap embankment completed as shown.

An extraordinary feature of this wall is that no metal is used in its construction; all fastenings of piles, binding frames, caps and planking being of oak or locust treenails up to 3 inches in diameter, as shown in Fig. 46.

The economy of this design, due to the small amount of expensive concrete in proportion to the size of the structure, deserves special attention.

This wall settles considerably, but does not move laterally to any great extent, notwithstanding the heavy pressure exerted on it. The maximum settlement has been about 4 feet and the maximum deviation from line about 6 inches. The movement is comparatively rapid for the first two or three years and then diminishes to something less than an inch a year. Movements of over one or two feet occurred only in a few short sections and the settlement in the greater portion of several miles of wall has been only a few inches. The settlement is corrected by building up the granite face on the wall from time to time and by raising the decks on the inner ends of the piers which sink with it. The extraordinary method of construction of this wall caused some criticism, and in 1896 a board of engineers reported as follows:

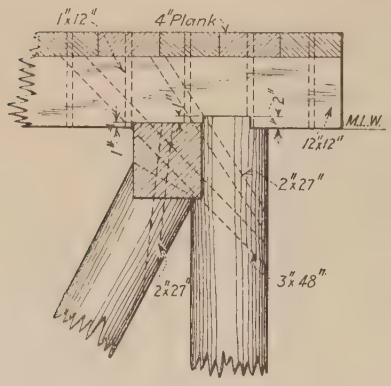

Fig. 46. Detail of Pile Connections showing Wooden Treenail Fastenings.

"To float a wall in mud when the wall must also take a horizontal thrust is a problem which can only be solved by care and experience, no formulas or mathematical rules being available. The wall, as now built, is a satisfactory solution of the problem. . . ."

There was no modification in the design of this wall, except the raising of the platform one foot above low water to increase the rapidity of construction, until 1899, when,

owing to decrease in the price of cement and increase in that of labor and lumber it was redesigned in order to lessen the cost. For this purpose the blocks were widened to $10\frac{1}{2}$ feet on the bottom, resting on four rows of piles instead of three, the binding frame and half of the bracing

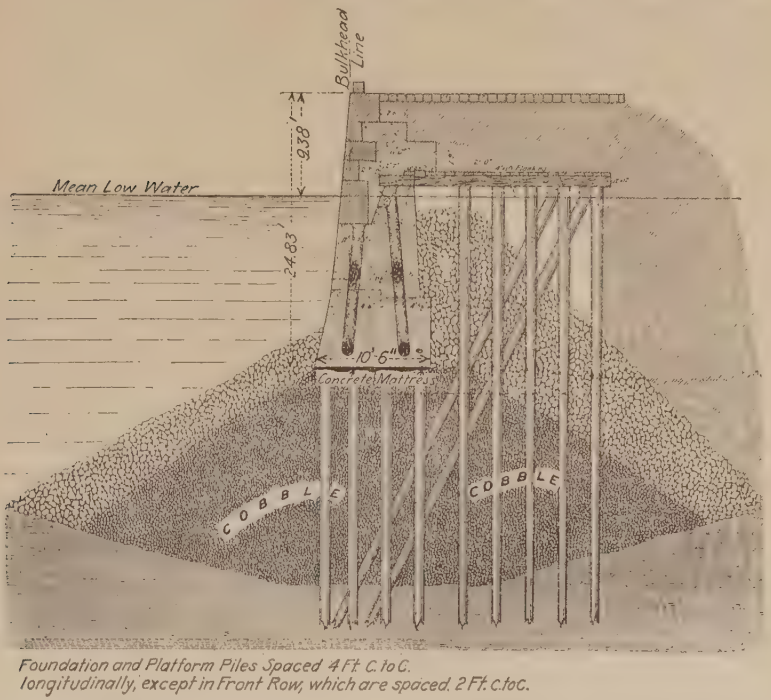

Fig. 47. Bulkhead Wall with Relieving Platform, Type of 1899, Dept. of Docks, New York, N. Y.

piles were omitted, and the amount of riprap and granite decreased.

Where this wall is built on hard bottom, but where rock is below the reach of piles of ordinary length, a relieving platform of concrete deposited under water instead of a timber platform has been used, as shown in Fig. 48. This design calls for less concrete than that shown in Fig. 21. A similar design for localities where the rock is located at such depths that a gravity wall is too expensive is shown in

Fig. 49. The use of bracing piles counteracts any tendency to move outward.

A relieving platform wall, with sheet-pile facing surrounding a solid-filled pier, 3000 feet long by 292 feet wide, at Chicago, Ill., is shown in Fig. 50. In this wall, which was built in water from 20 to 27 feet deep, the usual timber platform at low-water level and the gravity wall on the outer edge of it were combined in one structure of reinforced

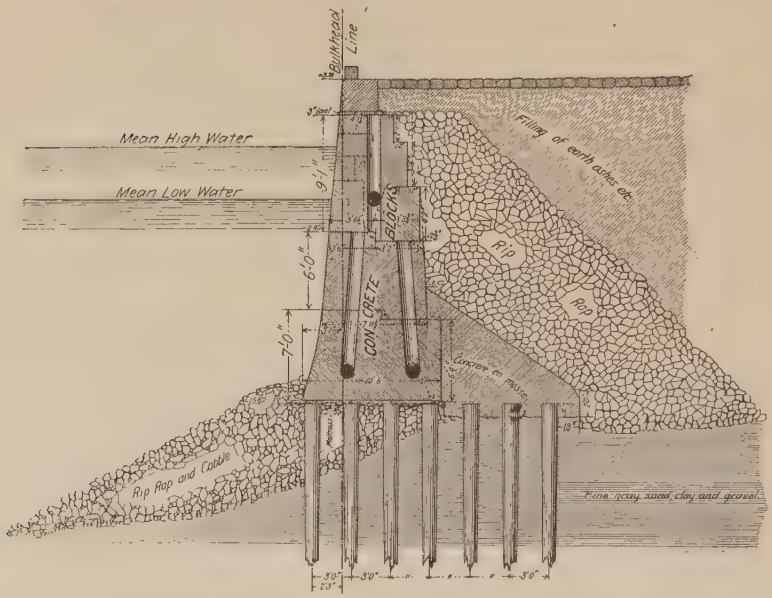

Fig.. 48. Platform Wall, East 23rd St., New York, N.Y.

concrete, $18\frac{1}{2}$ feet wide. The platform is supported by three rows of round piling and a row of 12-inch triple-lap wooden sheet piling. The three rows of round piles are tied together with rods located $2\frac{1}{2}$ feet below the water surface. Riprap was deposited outside of the sheeting to as great a height as possible without interfering with vessels mooring alongside. The outer rows of piles are spaced 4 feet apart and the interior rows 2 feet. In the outer portion of the pier there are tie rods extending from wall to wall. Three rows of wales give a bearing for the sheet piling

against the outer row of round piles, the lower wale or mud sill being of reinforced concrete. The piles were cut off about one foot above the normal water level and the space between them was filled with riprap from the Chicago Drainage Canal, up to the surface of the water. The area enclosed by the wall was filled partly by dipper and partly by hydraulic dredges. A sheet of canvas was placed on

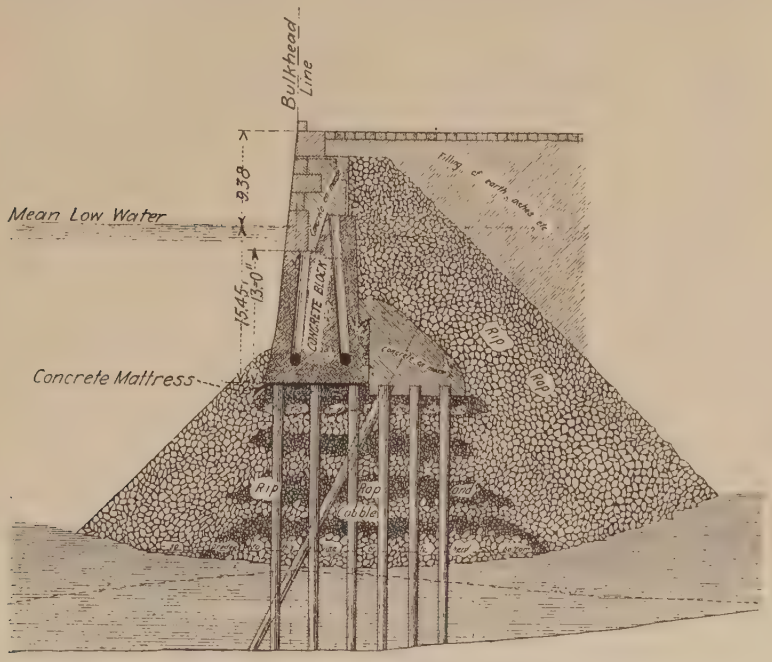

Fig. 49. Platform Wall, Rector St., New York, N. Y.

top of the riprap to prevent the concrete from leaking into the voids and from being washed out and the concrete wall built to $7\frac{1}{2}$ feet above the water level.

The relieving platform in this wall supports the outer edge of a reinforced concrete freight deck designed for the very low load of only 250 pounds per square foot, together with the columns of a passenger platform with a live load of 200 pounds. The thrust against the sheet piling is diminished by the bank of riprap.

This wall was criticised because it bulged with a maximum deviation from line of 18 inches, but it was decided by a board of engineers that the deformation of the sheet pile

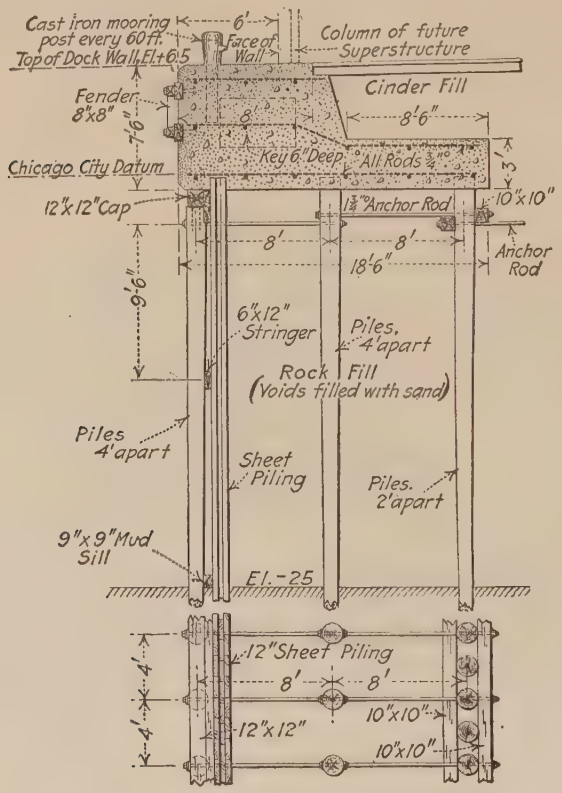

Fig. 50. Wall of Wooden Sheet Piling with Concrete Platform, Municipal Pier, Chicago, Ill.

and concrete walls affected the appearance only and not the safety of the structure.

The boring of the horizontal holes in the piles $2\frac{1}{2}$ feet below the surface of the water where the waves were often high and troublesome and the placing of the rods in the holes were accomplished by an ingenious device. Augers, driven by means of pneumatic boring machines, were

mounted in guides in a wooden frame which was suspended from guide timbers. The boring machines were arranged so that when the guide frame was in place they were above the water and were connected to the augers by inclined shafts and universal joints. The tie rods were placed by men clad in watertight rubber suits standing on a submerged raft.

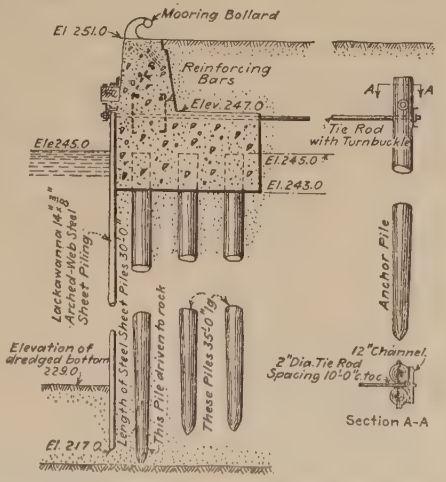

Fig. 51. Concrete Platform Wall with Steel Sheet-piling, Toronto, Ont.

A design somewhat similar to the foregoing, in which steel sheet-piling instead of wood is used, is illustrated in Fig. 51. In this case the relieving platform is only about 8 feet wide for 16 feet depth of water and the principal portion of the thrust is taken by the tie rods and anchor piles. The small area of the steel beam in rear of these anchor piles and the absence of bracing piles in the anchorage is noticeable.

Another design for a coal-loading wharf at Toledo, O., in which bracing piles are used to take some of the thrust, is shown in Fig. 52. This wall was built outside of an old one and the work was done in the winter when navigation was closed.

A relieving platform wall of reinforced concrete for an ore dock at Detroit, Mich., is illustrated in Fig. 53. The filling is retained by a low sheet-pile bulkhead behind a reinforced concrete platform 36 feet wide on oak piles, over the natural sloping bank of the river, without riprap or other revetment. The depth of water at the edge of the deck was about 15 feet. The platform, not being intended

for the landing of freight, was designed for a load of only 100 pounds per square foot. The heavy, longitudinal girders carry tracks for an ore unloading machine, the main tower of which spans the platform. The relieving platform carries a railroad track and the ore floor, the portion under the latter being designed to carry 6800 pounds per square foot. The piles were cut off 3 inches above the water line and the concrete girders extend 6 inches below it. The fendering system consists of a line of spring piles and an oak fender on the outer edge of the platform slab. Patents on the general features of this

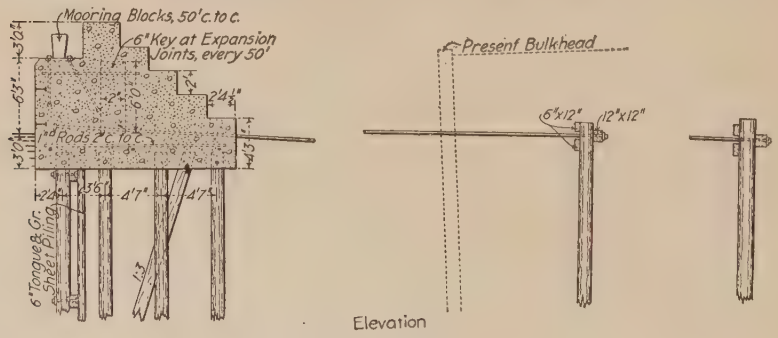

Fig. 52. Wall with Wooden Sheet Piles and Concrete Platform, Toledo, O.

wall are held by S. D. Carey, Cleveland, O. A somewhat similar wall, constructed at Cleveland under the same patents is shown in Fig. 54.

Another wall of similar type for an ore dock at Cleveland, is shown in Fig. 55. The piles under the wall, except those in the front and rear rows, were cut off at mean low water. The anchorage consisted of old rails which, together with the tie rods, were entirely buried in concrete to prevent any possible corrosion. Oak piles were used throughout. This wall had to support heavy heaps of ore immediately in the rear of the platform.

A novel method of capping piles, cut off below low-water level, was used at Hamilton, Ont., on a wall built with a narrow relieving platform supported by transverse, braced

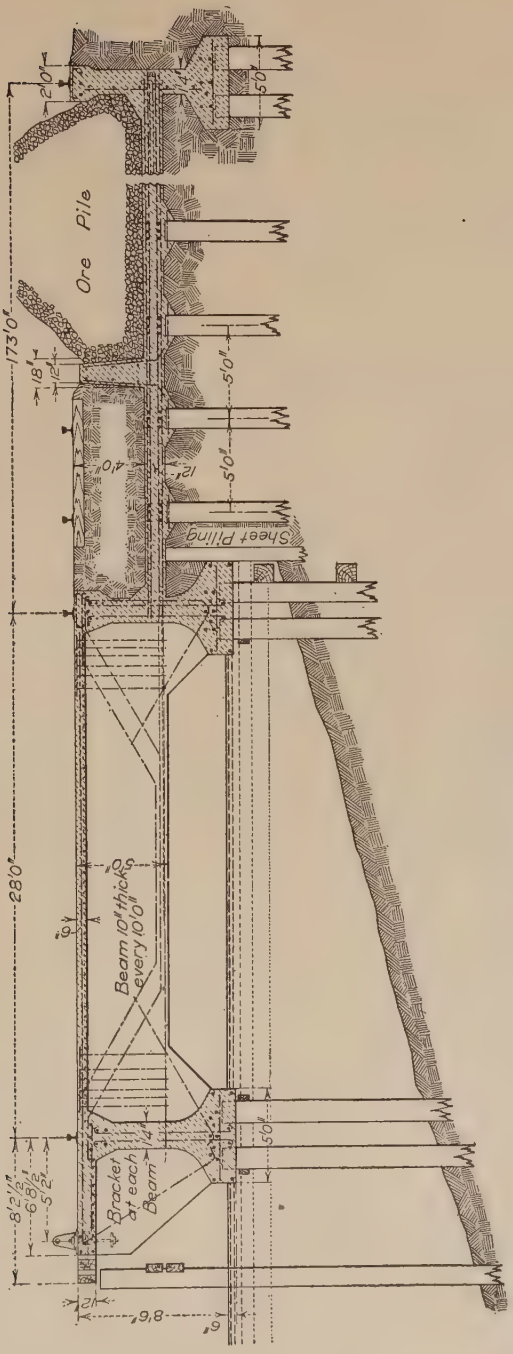

Fig. 53. Platform Wall, Detroit, Mich.

pile bents, which also afford lateral support to sheet piling, as illustrated in Fig. 56. This wall was built out in the water at some distance from the natural shore line. The work of capping and bracing the piles is usually performed by divers and is slow and expensive, particularly where the water is rendered turbid by sewage or other causes. In this case a floating caisson or diving bell was used to cap the piles, which were driven down some two feet below low lake level and cut off at three feet below that elevation. The water was depressed to a depth of about 6 feet, and the air pressure was therefore

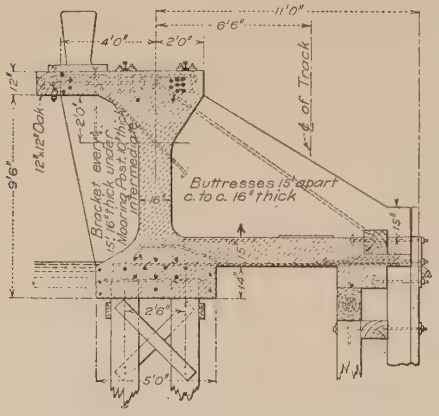

Fig. 54. Platform Wall, Cleveland, O.

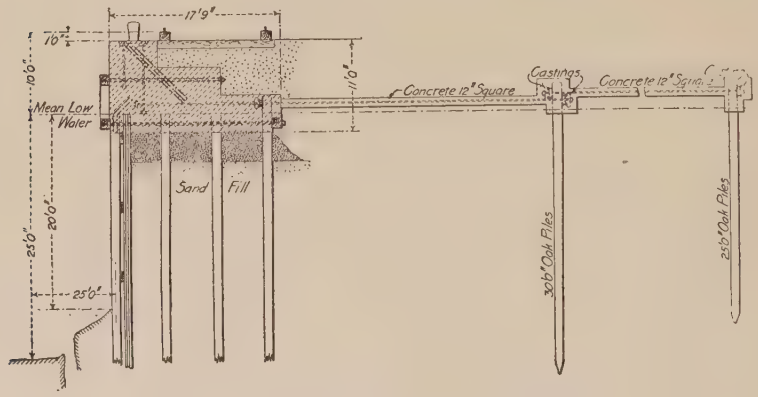

Fig. 55. Platform Wall with Wooden Sheet Piling, Cleveland, O.

only about 3 pounds per square inch. The longitudinal alignment of the piles was effected by timber clamps, placed below the caps and tightened by wire ropes, operated by a hoisting engine, as shown in the illustra-

tions. Steel sheet-piling at the face of the wall was used to retain the filling. An interesting comparison could be made between this design and one in which the horizontal thrust is taken by bracing piles instead of by the plank braces put in place by divers.

A design for a relieving platform wall at Jacksonville, Fla., with a vertical facing of steel sheet-piling is illustrated in

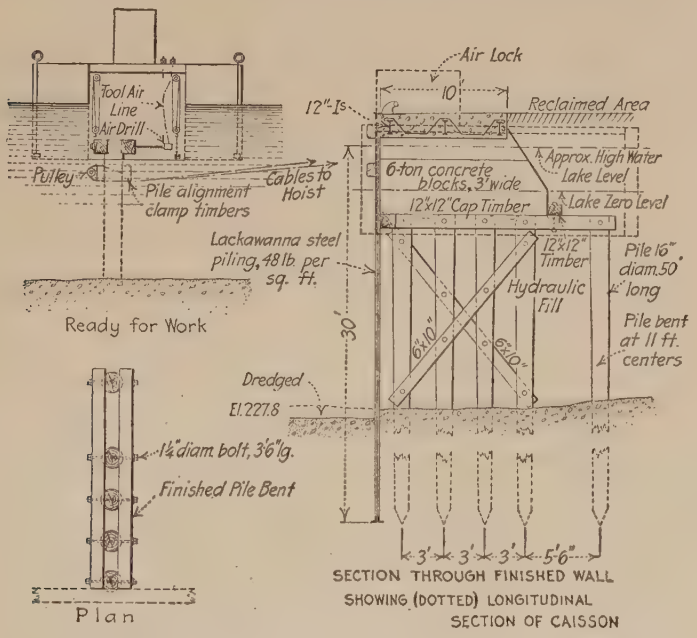

Fig. 56. Method of Capping Piles for Platforms, Hamilton, Ont.

Figs. 57 and 58. The sheet-piling is supported by I beams driven into the shell rock of the bottom and is protected from corrosion by concrete deposited by means of a tremie. The I beams are spaced 4 feet apart and are tied at low-water level to inclined pile anchors located 39 feet in rear of the face of the bulkhead. The timber relieving platform is 18 feet wide and is designed to carry a live load of only 200 pounds per square foot in addition to the weight of the filling. This platform reduces the thrust on the sheet

piles and tie rods to the sum of that of the filling above the platform and that of the pressure wedge below the platform,

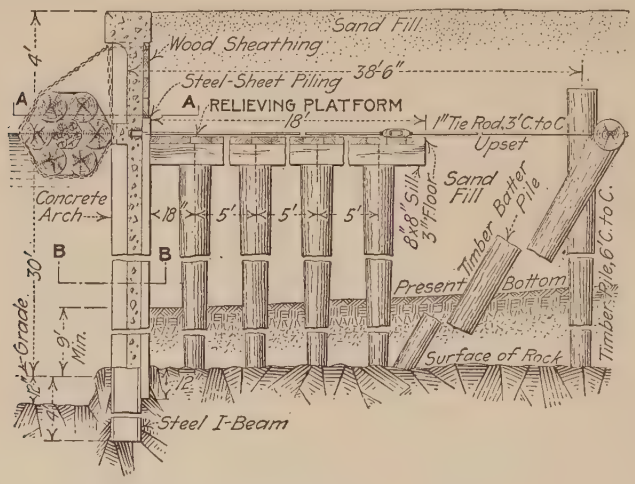

Fig. 57. Platform Wall, Jacksonville, Fla.

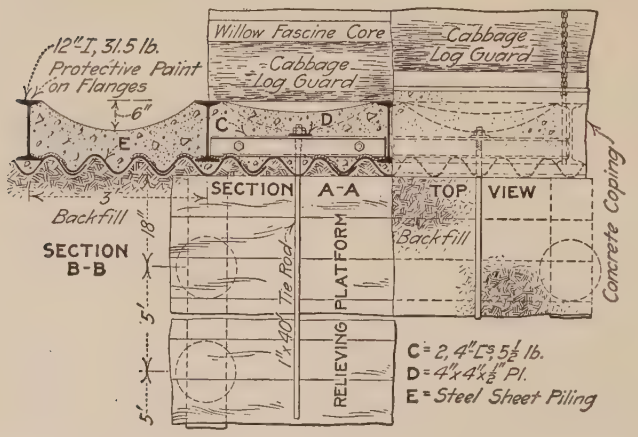

Fig. 58. Horizontal Section of Fig. 57.

which is diminished by the resistance of the platform piles. This wall is planned for a depth of water of 30 feet below mean low tide and a height of only 4 feet above it.

Sheet-pile Walls

Sheet-pile walls, for purposes of classification, may be defined as those in which the material behind the wall is retained by a row of sheet piling, supported against the pressure of the filling by the resistance of the material into which the piles are driven, and by tie rods running back to anchors of various patterns embedded in the earth in the rear, or by bracing piles in front. Those in which sheet piling is used in conjunction with a platform have been classified as platform walls. The great advantage of sheet-pile walls lies in their cheapness, simplicity, and the ease and rapidity with which they may be constructed. Those that are of timber decay above water in a few years and then have to be torn out and rebuilt or repaired by driving another row of sheet piling outside the old one. In many cases the latter method is impossible, owing to the restrictions of the harbor authorities, property lines, and to the undesirability of narrowing slips and waterways. Because of its lack of durability and the cost of rebuilding, the use of wooden sheet-pile walls for important structures has of late years been abandoned in favor of those of concrete or steel, or of those in which a relieving platform is used. The use of unprotected steel sheet-piling in fresh water has increased greatly in the last few years.

Sheet-pile walls are especially suited to places where it is necessary to build a wall close to existing structures.

The reliability of this type of wall depends largely on the nature of the support for the upper portion of the piling. For this purpose nothing can compare with bracing piles, and anchors for tie rods of which bracing piles do not form a part are, in many cases, most objectionable on account of the uncertainty of the horizontal compressibility of the material in which they are placed or of its safe angle of repose.

One of the simplest forms of wooden sheet-pile bulkhead was used for many years in Chicago and is shown in Fig.

59. A row of round piles was driven along the bulkhead line, a mud sill and two or more wales placed in the rear of these, and sheet-piling driven against the sills and wales. The round piles were tied with rods to deadmen in the rear of the wall. For temporary structures, requiring no very great depth of water, in the firm, tenacious clay of the Chicago district, this design is sufficiently good. It is also exceedingly cheap.

A simple form of steel sheet-pile wall was used for the

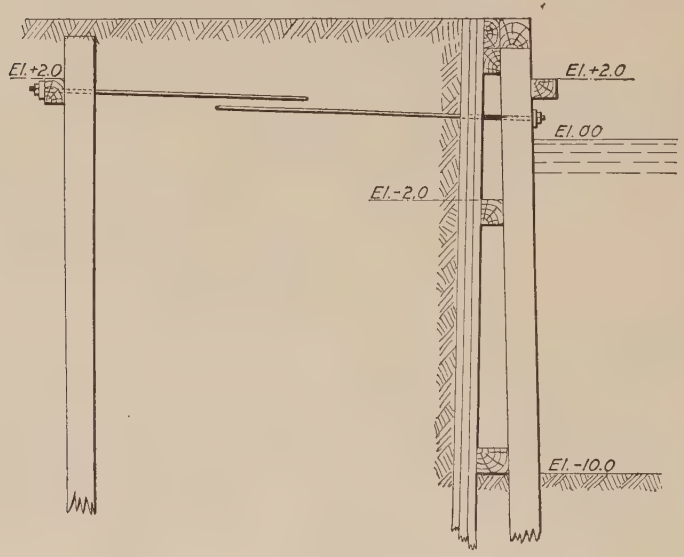

Fig. 59. Sheet-pile Wall, Chicago, Ill.

approach to the ship lock at Blackrock, Buffalo, N. Y., and is shown in Fig. 60. In this case the required depth of water was 23 feet. A row of painted, interlocking steel sheet-piling of the arched form, which gives a very high bending moment, was driven 10 feet below the bottom of the canal and tied back to a pile and wooden beam anchorage, with rods placed some 2 feet above mean lake level but above the water surface at the time they were placed. Two lines of wooden wales or fender timbers completed the structure. This wall acts simply as a retaining wall on

the approach to a canal lock, and does not have to carry any great surcharge of freight or other live load. Bracing piles were not used in the anchorage.

A steel sheet-pile wall, founded on rock, was built for a coal pier for the Pennsylvania lines at Sandusky, Ohio. The sheet-piling is supported by reinforced concrete piles spaced 8 feet, 9 inches, apart, dowelled to the rock with old car axles. The concrete piles and the steel sheet-piles are embedded in the bottom of a light, concrete gravity wall, 8 feet high, extending one foot below mean lake level. At the middle of the panel between the concrete piles, pairs of 2-inch rods are attached to the heads of the steel sheet-piling with washers made of old rails and are fastened, at the opposite side of the pier, to an old dock wall. The rods are encased in concrete to prevent any possible corrosion. The piles are octagonal in section and 18 inches in diameter. They are reinforced with vertical rods and hooping and have moulded into them the two halves of a split sheet pile and a 6-inch pipe. Through the pipe the hole for the dowel was drilled into the rock after the pile was in place and the car axle then dropped down through the pipe and grouted into the rock. There were 18 feet of water over the rock at this pier. Fig. 61 shows the construction.

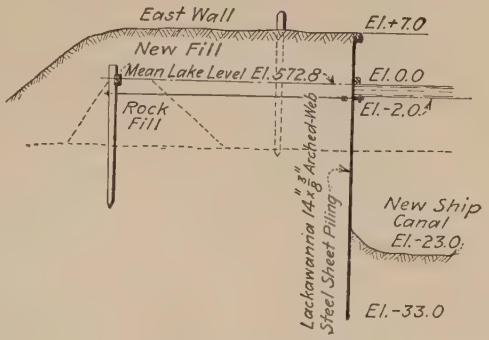

Fig. 60. Steel Sheet-pile Wall, Black Rock, Buffalo, N. Y.

Another wall of extraordinary height founded on rock, though not strictly a sheet-pile wall because the sheeting is horizontal instead of vertical, was built for the same railroad at Ashtabula Harbor, Ohio, and is shown in Fig. 62. The channel bottom in this case was 23 feet below

mean low water and the wall had to support one side of a fill about 62 feet wide, carrying four standard tracks for heavy coal cars, at an elevation of 17 feet above mean lake level. The posts in this case were made of two 18-inch I beams, spaced $7\frac{1}{2}$ feet apart, extending into the rock 4 feet and tied to concrete deadmen at the opposite side of the high fill with $2\frac{1}{2}$-inch rods. Horizontal sheeting of 6-inch by 12-inch lumber was placed behind the posts, from the rock to 18 inches below mean lake level and above the

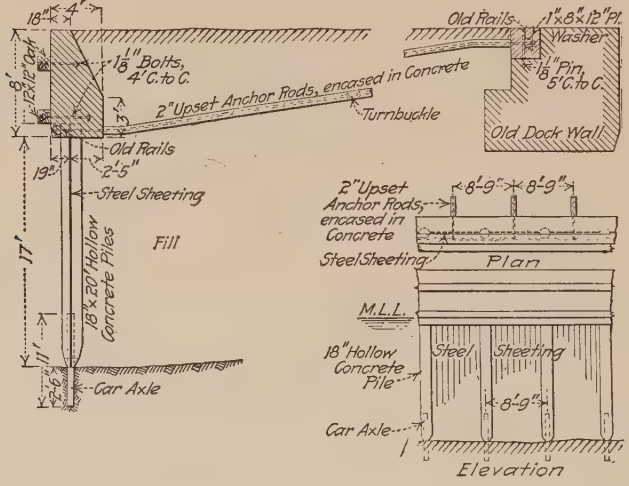

Fig. 61. Steel-sheet Pile Wall, Sandusky, O.

wooden sheeting reinforced concrete slabs 6 inches thick, cast in place, were used. At the bottom of the wooden sheeting bags of mortar were placed to make a seal to prevent the filling from washing out. The holes for the posts were 24 inches in diameter and were drilled with a large steam drill with a special form of bit. The space between the posts and the sides of the holes was filled with concrete, which was sent down in bags to divers, who opened the bags and placed the concrete in position.

The rock behind this wall extended up nearly to the water line, so that the thrust of the filling was much less

than it would have been if the rock behind the wall had been at the same elevation as in front.

This design was considered superior to that of an adjacent

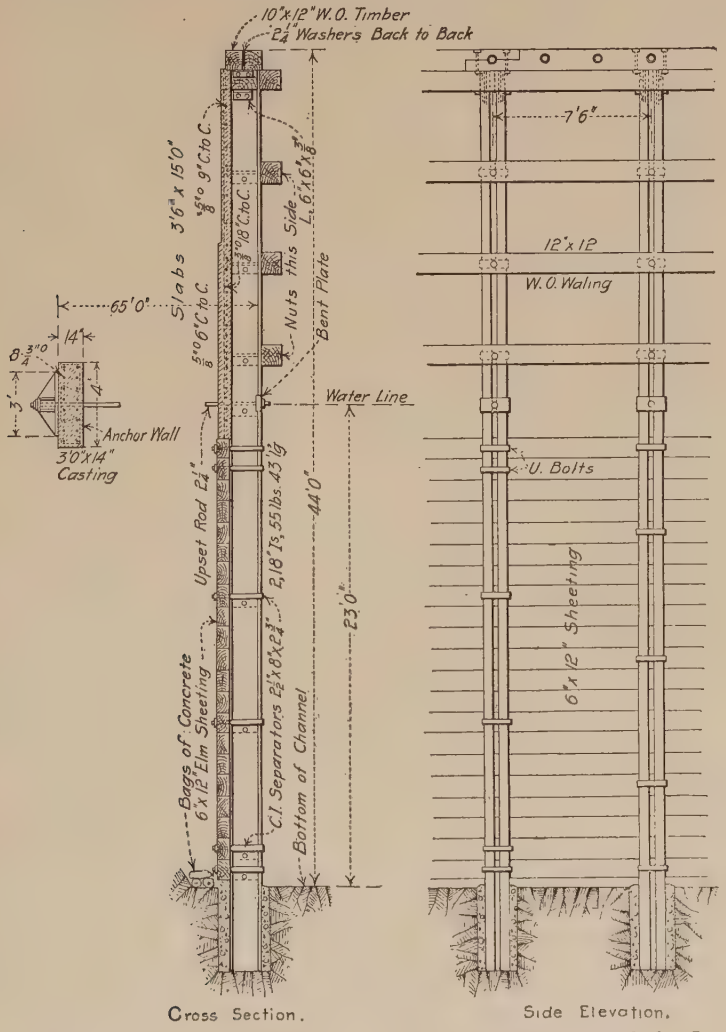

Fig. 62. Wall of Steel Posts with Wooden Sheathing, Ashtabula, O.

wall in which vertical sheeting was used, in that it did not require any horizontal wales below the water line, the placing of which was somewhat difficult.

Another steel sheet-pile wall was built for a terminal or freight warf on the summit level of the Barge Canal at Rome, N. Y. (See Fig. 63.) In this case the portion extending from the top to 2 feet below the normal water level was encased in concrete which was bounded to the sheet-piling with steel bars. A continuous anchorage beam of reinforced concrete was provided and the tie rods were encased in concrete to prevent corrosion. The only portion of this wall exposed to rust is the outer face of the sheet-piling the heads of the tie rods and the steel wales through which the rods project. These can be examined and painted if necessary, as the water can be drawn from the canal in the winter time when navigation is closed. There was a considerable saving in the excavation in this type of wall over the platform type. The channel in front was excavated after the wall was completed.

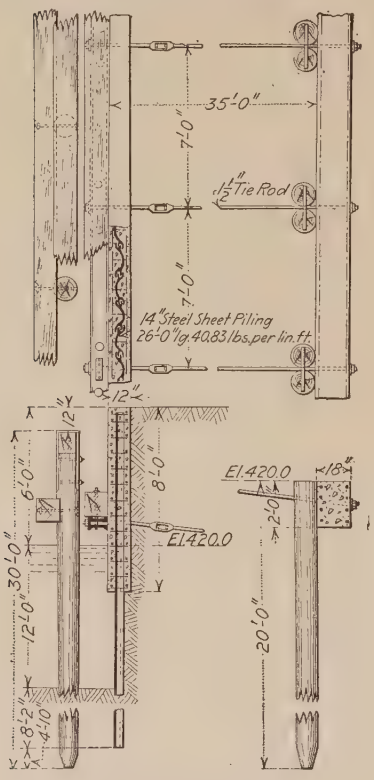

Fig. 63. Steel Sheet-pile Wall Barge Canal, Rome, N. Y.

A reinforced concrete sheet-pile wall illustrated in Fig. 64 has been built to enclose several large solid-filled piers in Baltimore. The previous type of wall consisted of wooden sheet-piling with a wooden platform on piles having a stone masonry wall on its outer edge; but the prospect that the teredo, which had been driven from the vicinity by sewage, might return after the construction of a sewage-disposal plant which was under consideration, together with the fact

that the type of wall in use required a large amount of dredging, made it appear advisable to build a wall entirely of concrete and steel. Steel cylinders with parallel sides and semicircular ends, 10 feet long, 3 feet wide, and about 29 feet high, were sunk 25 feet apart to a hard gravel bottom approximately 22 feet below low water. The cylinders were tied across the pier to those on the opposite side, or, whenever the distance was too great or buildings interfered, to concrete deadmen. Passing through the cylinders, above the water line, were horizontal steel lattice girders wrapped with wire mesh and encased in concrete. Back of these girders, reinforced concrete sheet piles, 12 inches by 18 inches in section, were driven with their heads bearing against the girders. Another steel girder, encased in concrete, was placed on top of the cylinders at the front edge and supported one side of a reinforced concrete slab, the rear of which rested on a reinforced concrete wall built on top of the sheet piling. This slab carried a cobblestone pavement and on its front edge a concrete curb.

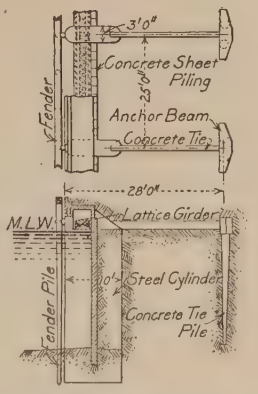

Fig. 64. Concrete Sheet-pile Wall, Baltimore, Md.

The steel cylinders were sunk in a trench, dredged to 15 feet depth, by jetting and driving with a steam hammer mounted in a specially constructed steel frame resting on top of the cylinders. Some of these were put in place without much difficulty, but many obstructions, such as old wooden sheet piling, cast-iron pipes, lumps of brick masonry and logs, were encountered. These had to be removed by divers or by men working from the inside of the cylinders, where it was possible to keep the water down by pumping. The narrowness of the cylinders made such work extremely difficult.

The concrete sheet piles were not grooved or dovetailed and were bevelled in one direction to make them drive

close together. They were driven by jetting and steam hammers. It was not always possible, however, to make them fit closely, and in some cases narrow piles were driven in the interstices, and in others additional piles were driven in the rear of the gaps.

This wall is said to have cost only $58.00 a linear foot exclusive of dredging and $87.00 inclusive of dredging.

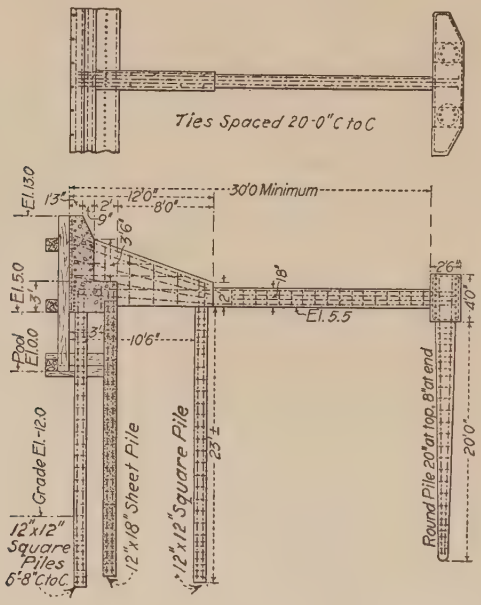

Fig. 65. Concrete Sheet-pile Wall, Raymond Patent, Barge Canal, Albany, N. Y.

A sheet-pile wall entirely of reinforced concrete has been designed and successfully built, in many places, by the Raymond Concrete Pile Co. Some of the features are patented. This wall consists of a line of reinforced concrete sheet piles with their heads supported by a horizontal girder, located above the water line, which rests on a row of concrete bearing piles some three or four feet in front of the sheet piles. The girder carries a vertical facing wall which is held against the overturning forces by buttresses

supported on a row of piles in the rear. The whole structure is tied back to concrete deadmen. This design, though expensive in comparison with other types, is efficient where it is absolutely necessary to use concrete for the whole structure, but rather extravagant in the use of concrete for ties and anchor piles. The use of concrete for this purpose is justified, however, in some non-tidal waters where the anchor piles cannot be cut off low enough to ensure their safety from decay. A wall of this type at the Barge Canal Terminal at Albany, N. Y., is shown in Fig. 65.

CHAPTER V

PIERS

Comparison of Types

Of the three types of piers — pile-platform, block-and-bridge, and solid-fill — the first is usually the most advantageous in localities where the water is not too deep and the bottom is suitable for piles. It offers less obstruction to the free flow of water, sewage, and ice, does not materially affect the tidal prism, may be rapidly constructed, and may be readily altered, removed, or enlarged. In piers of ordinary proportions of length to breadth, where marine borers are not active, it is usually cheaper than the filled-in type.

The block-and-bridge model is rather limited in its application, as it is economical only for small piers in shallow water and on hard bottom. It has the advantage that if the blocks are of cribwork it may be built without the use of expensive equipment, such as pile drivers and floating derricks.

The solid-filled type of pier may be used where the obstruction to the flow of the water, sewage, and ice and the diminution of the tidal prism are not serious objections. It has been urged that a large vessel lying alongside a pile pier offers nearly as much obstruction to the flow of water as a solid-filled pier, but it is to be remembered that in tidal waters the bottom of the ship is near the bottom of the slip only a portion of the time and that for some portions of the time, parts of the pier are not obstructed by ships, thus permitting the flotsam, ice, etc., which accumulate in a slip to pass away. The disadvantage of

the solid-filled piers, especially where they are built in groups, is, in this respect, real and important.

Filled-in piers may have greater stability than pile piers, depending on the nature of the retaining structure, but when so built are liable to do more damage to vessels which may collide with them.

The comparative cost of pile and filled-in piers depends on the local conditions and on the ratio of the length to width of the pier, the filled-in type having the advantage where the width is very great. For piers in Brooklyn 1300 to 1800 feet long, the filled-in type with one-story sheds was considered cheaper for widths over 100 feet; and in Philadelphia, for a length of 550 feet, the economical limit for pile piers with two-story sheds was estimated at 200 feet.

The comparative durability of a filled-in pier depends on the nature of the retaining structure. If this structure is of the same nature as that of the sides of a pile pier, there is, when decay is the only agent of destruction, very little advantage in favor of the filled-in type, as the interior portion of a carefully designed pile pier is very durable, especially if it is covered with a shed. Where there are borers, however, a solid-filled pier may be surrounded by a cheap non-permanent type of marginal construction affording a smaller area subject to the action of the borers than in an open pile pier.

One of the most important objections to the filled-in type is the length of time required for construction and the time required for the filling to settle so as to furnish a stable support for a smooth and level flooring or pavement, which is essential for the economical use of freight-handling trucks, either hand-operated or electrical. The solid-filled pier, however, will ordinarily support a comparatively heavy live load on those portions of the floor not near the edge.

Filled-in piers are less combustible than wooden-pile piers in that, even when surrounded by a timber platform, the timber forms only a small portion of the structure.

The filled-in type has a great advantage whenever a large amount of excavated material has to be disposed of, in that it affords an economical method of utilizing such material. This is usually the case, as such piers are generally located where the water is shallower than that required for shipping and dredging is required in the adjacent slips and channels. Filled-in piers are, however, sometimes built in deep water, as at Victoria, B. C., where the depth is 60 feet.

Pile-platform Piers

Classification. — The pile-platform type of pier may be subdivided into various classes, according to the nature and material of the piles and platform as follows:

1. Wood piles extending up to deck.
   - *a.* Wood caps and deck.
   - *b.* Wood caps, concrete decks.
   - *c.* Concrete caps and deck.
2. Wood piles cut off near low water.
   - *a.* Earth or cinder fill on platform.
   - *b.* Reinforced concrete posts or cross walls, concrete deck.
3. Composite piles of wood and concrete.
4. Metal piles or cylinders.
   - *a.* Cast-iron piles.
   - *b.* Wrought-iron or steel piles.
   - *c.* Wrought-iron or steel cylinders.
   - *d.* Cast-iron cylinders.
5. Reinforced concrete piles.
6. Reinforced concrete columns.

There are other possible combinations of different kinds of piles and platforms, some of which are described in this chapter.

Advantages of Different Classes. — Wooden piles, unprotected against marine borers, are not suitable, except for temporary structures, in waters in which these animals are present. If a pier is built on creosoted piles it may be

expected that some of the piles will need renewal at the end of 12 or 15 years, and as the worm-eaten portion cannot be replaced without replacing the whole pile, they must be removed and replaced or additional piles driven and pulled under the caps. This requires the removal of a portion of the deck and, if there is a shed on the pier, the removal of a portion of the roof. On the other hand, where borers are absent, the various types in class 1 are suitable and economical, as the portions of the piles subject to decay can be replaced by splicing on new pieces. The prices for materials and other local conditions in New York have caused this class of construction to be used in building the municipal piers in that city. The building of wooden-decked piers has been abandoned as far as possible in favor of those with a reinforced concrete deck, as the wooden deck is the part of the structure which requires the largest amount of repairs and the cost of the concrete deck is very little more than that of wood. This type, however, is not used on deep mud bottom where settlement of the structure is expected. In such locations a thin layer of reinforced concrete is placed on a plank deck and where great settlement is anticipated no concrete is used at all. This type of construction is, however, subject to a fire risk from floating oil, cotton bales, etc., which may drift under the pier.

In Philadelphia conditions as to borers, tides, shipping, etc., are similar to that in New York and in designing municipal piers the Department of Docks and Ferries obtained bids on six different types of construction in order to obtain a comparison of costs. The bids showed a difference of only 8 cents a square foot, or a little over 3% between the design similar to that used in New York in which the piles extend up to a reinforced deck and one in which the piles were cut off about three feet above mean low water and supported square concrete posts or columns carrying reinforced concrete beams and deck as in class 2*b* in the table above, and illustrated in Fig. 76.

. In considering the design of the New York type it was estimated that the tops of all the piles would have to be renewed in 10 or 15 years. This is very different from the New York estimate that only $33\frac{1}{3}\%$ would have to be renewed every 20 years. As the difference in cost would not pay for splicing the number of piles that it was thought would require renewal within the commercial life of the pier, and as the latter type required no renewals and was free from the fire risk, it was adopted. Another variation of the same general type in which the deck is supported on concrete walls extending from side to side of the pier was also used. It is interesting to note that in spite of the above, recent piers in New York City are being built on a plan similar to that in Fig. 70 with the exception of the addition of side caps. The contract price for these piers is about $1.20 per square foot, including the asphalt pavement, which is less than one half the cost of the Philadelphia piers. It must be remembered, however, in making the comparison, that the New York piers were designed for one-story sheds and those in Philadelphia for two stories with very heavy live loads which required heavier column foundations and more piles.

Concrete pile piers have a disadvantage in comparison with those of wood in that it is difficult to brace them transversely. With wood piles it is easy to apply horizontal braces just above mean low water and diagonal braces between them and the caps, thus forming a truss several feet deep. This, so far, has been practically impossible with concrete piles, and they have been braced entirely with inclined piles or by deepening the caps so as to reduce the length of that portion of the piles subject to bending.

A difficulty is found in the construction of piers with concrete superstructures, in the support of the forms for the girders, joists and deck, which are often of very long span, and in the removal and transfer of the forms from bent to bent. Steel beams encased in concrete have been used in many cases instead of reinforced concrete for these

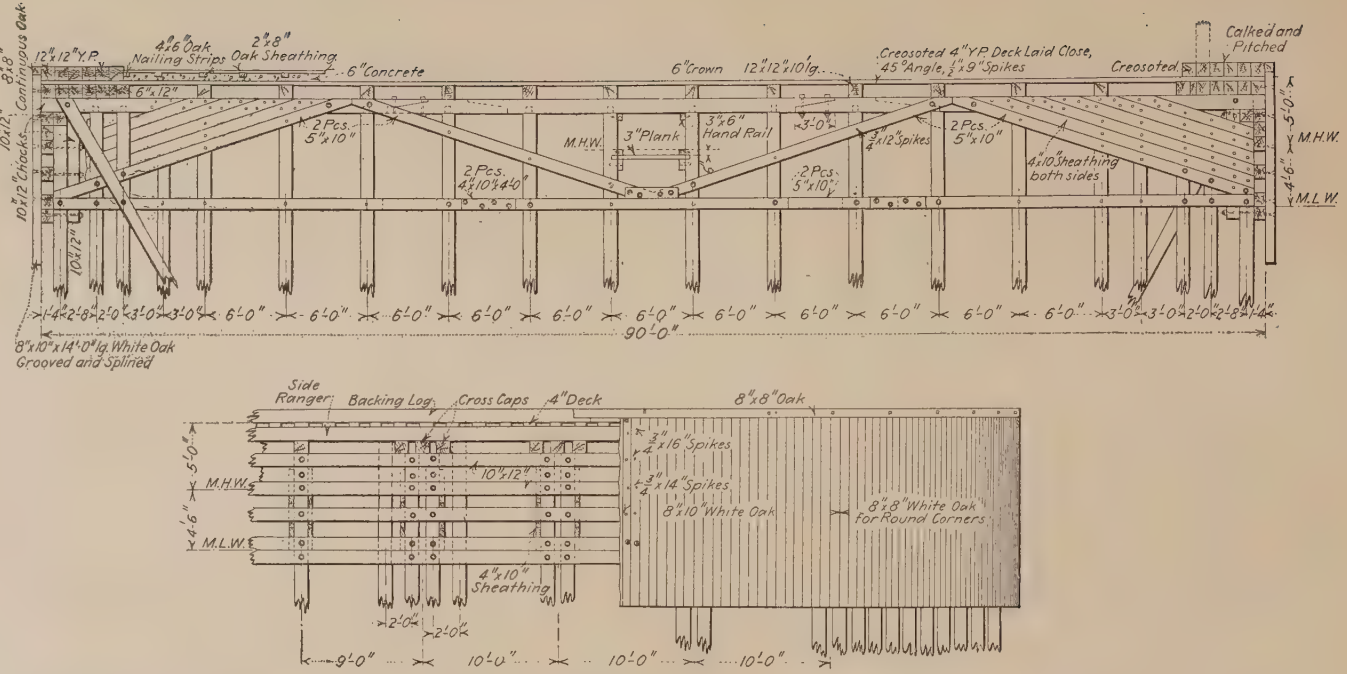

Fig. 66. Cross Section of Heavy Wooden Piers, and Elevation of Outer Corner, North German Lloyd Co., Hoboken. N. J.

members, as they support themselves as well as the forms for the deck.

Piers with Wood Piles Extending up to Deck. — While reinforced concrete may be more economical than timber for piers where the estimated life of the structure is taken at fifty or seventy-five years, it usually cannot compare in economy with timber for an estimated life of forty years. For this reason there will always be a demand for good wooden piers whenever lumber of good quality can be

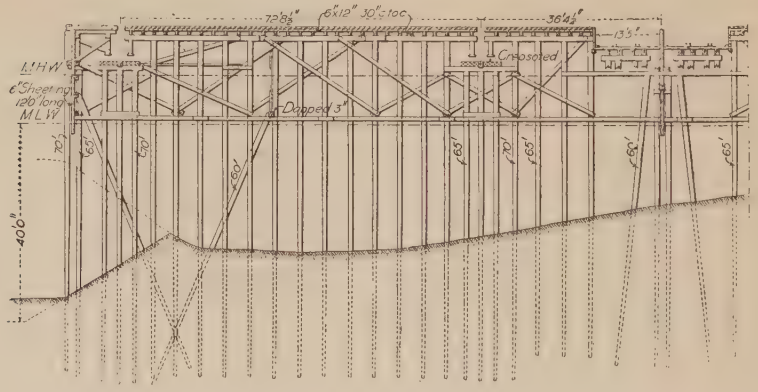

Fig. 67. Pier with Wooden Piles and Deck. B. & A. R. R., Boston, Mass.

obtained at low prices, as on the Pacific Coast and on the Atlantic since the opening of the Panama Canal.

An excellent example of a pier of the class designated in the table as No. 1a, of a type adapted to general use is that described in Chapter III. This design, after over forty years of experience, has undergone little alteration and is still used where the concrete deck is not desirable.

The North German Lloyd Steamship Company's piers, which were built to replace those which were destroyed in the great fire in 1900 are chiefly notable for the vertical sheathing on the outside, extending from the deck to low water and for the layer of concrete on the wooden deck which was added for fire protection. This concrete carried

a wearing surface of plank. A section of these piers is shown in Fig. 66.

Piers of this class on the Pacific Coast differ notably from the above in the use of 2-inch by 14-inch joists for supporting the deck instead of 12-inch by 12-inch "rangers."

In 1910 the Boston & Albany Railroad constructed several piers at East Boston to replace those destroyed by fire, the main features of which are shown in Figs. 67 and 68.

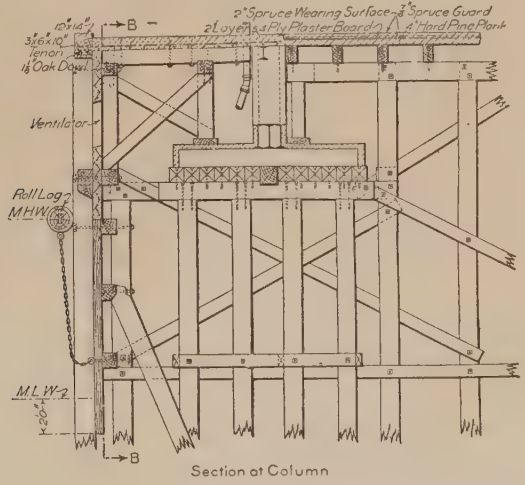

Fig. 68. Portion of Fig. 67 enlarged, showing Column Foundation, Ventilator, Floating Fender and Details of Deck.

The larger piers are about 770 feet long and 250 feet wide, and the slips between them were dredged to 35 feet at low water. A part of the central portion of them consists of a natural bank of earth extending up nearly to the elevation of high water. The general construction is of timber with wooden piles. Inclined piles were used freely and the ten-foot range of tide with the deck at $10\frac{1}{2}$ feet above mean high water permitted the use of efficient transverse bracing on the vertical piles. In one of the piers the piles are cut off 2 feet above mean low water and capped, the deck being supported on posts resting on the caps, this saving in the

length of the piles and providing an easy method of replacing a portion of the structure subject to rot.

These piers were designed with the purpose of providing cheap, durable, and economical structures. Great attention was paid to fire protection and the prevention of rot. A line of sheet piling was driven all around the earth cores of the piers to protect the sloping banks from erosion. From high water to low water the sides of the piers are sheathed with heavy planking to exclude burning oil and other floating materials. This sheathing is surmounted, between high-water mark and the deck, with vertical, reinforced concrete slabs 4 inches thick.

Thorough ventilation is provided in order to prevent as far as possible the decay of the timber. This is accomplished by openings $2\frac{1}{2}$ feet by $3\frac{1}{2}$ feet spaced 9 feet apart in the concrete slabs and by ventilators on the sides of the track pits. A novel feature is the provision of an inspection walk under the deck to facilitate the observation of the condition of the structure, particularly in regard to decay. The decks are of concrete outside the sheds and inside they are of unusual construction, being formed of a layer of 4-inch plank on which are placed two layers of four-ply plaster board, a protecting layer of $\frac{7}{8}$ inch spruce, and a renewable wearing surface of 2-inch spruce.

The details, fastenings, and bracing of these piers were designed with exceptional care and thoroughness.

In designing a large State pier for New London, Connecticut, shown in Fig. 69, a combination of various types of construction was selected. The pier consists of a filled portion 100 feet wide surrounded by a pile platform 50 feet wide. The filled-in portion only is covered by a shed. The pile platform is built of creosoted piles, caps, and bracing, which support a deck of pre-cast reinforced concrete slabs, each 23 feet long and 6 feet wide, weighing about 7 tons. The slabs rest on the pile clamps, but are not fastened to them in order that the structure may not be so rigid as to injure vessels. On the slabs is a 2-inch asphalt wearing surface.

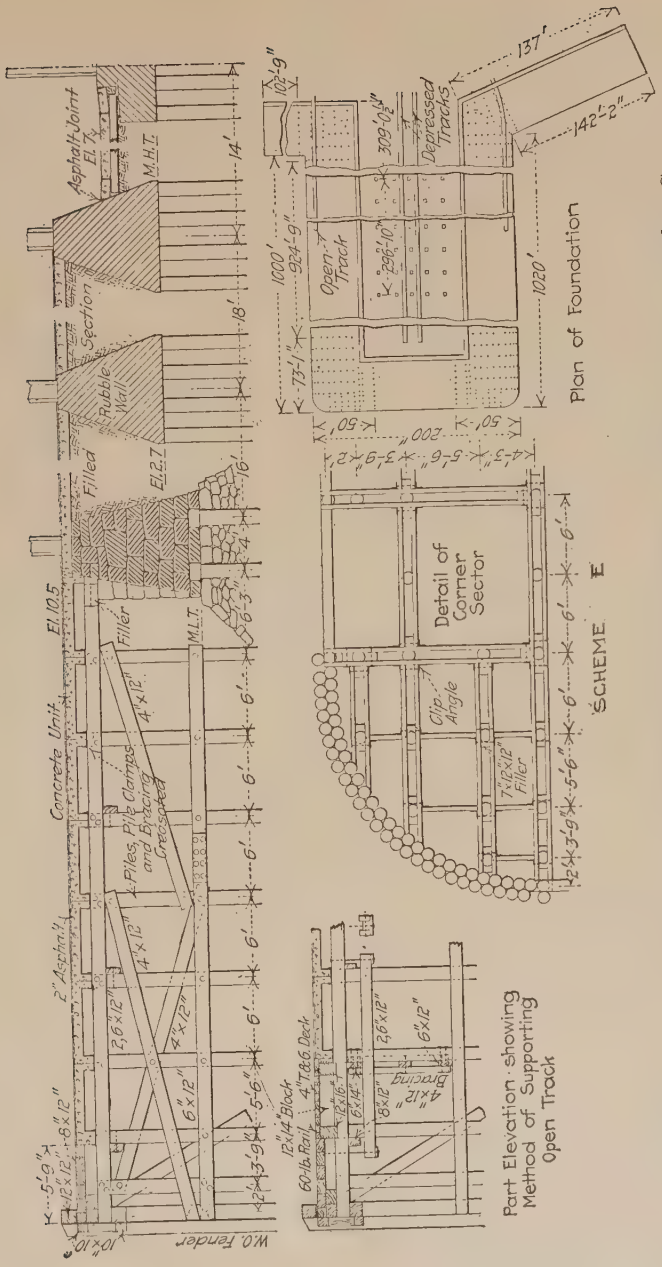

Fig. 69. Pier Platform with Creosoted Piles and Reinforced Concrete Deck, New London, Conn.

The shed on the filled-in portion of the pier is to be used as a warehouse and not merely as a pier shed for the temporary storage of cargo in transit between the ship and warehouse. The function of the pile platform is merely that of an unshedded pier with railroad tracks on it. The absence of the necessity for covering the platform with a shed had a decided influence on the design, in that, as the shed does not cover any portion of the platform and as the slabs can be removed at comparatively small expense, any portion of the piles or timber structure may be repaired or renewed without destroying the deck or the roof.

The retaining walls for the filling are of riprap surmounted by rubble walls on piles. The method of obtaining a uniform bearing for the masonry on the foundations is interesting. The piles were driven first, and the riprap was put in place around them. Quarry stones were then placed on top of the riprap in such a way as to form a channel on top of each row. This channel was lined with waterproof paper, forming a mould in which was cast a reinforced concrete girder, which conformed to the tops of the piles, no matter how uneven they were either in line or elevation.

The design adopted for this pier was based on the investigation of four different types: these were (*a*) steel cylinders filled with concrete supporting steel beams encased in concrete; (*b*) concrete piles and deck; (*c*) wooden piles, with wood deck and concrete sheathing and (*d*) creosoted piles cut off at mean tide and supporting inverted concrete boxes which formed the deck. The economy of the design was calculated on the assumption that the commercial life of the structure would be only twenty-five years. The total cost for the purposes of making the comparative estimates was considered to consist only of the original cost and the serial sum of the interest on the investment, and the annual average maintenance charge.

One of the first of five large piers built with wooden piles, wooden caps, and concrete decks is that at 33d Street,

Brooklyn, N. Y. It is shown in Fig. 70. In this design the wood is reduced to a minimum, even the side caps which in the previous designs of the New York Dock Department were placed on the side piles below the cross caps or clamps were omitted. The cross rows of piles, spaced 10 feet apart, were braced and clamped in the usual manner, except for the omission of the side caps and the addition of four rows of longitudinal bracing which were found

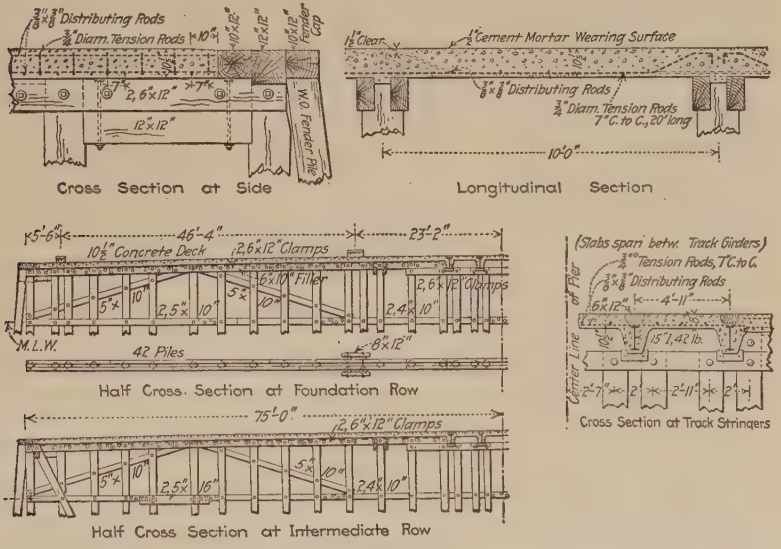

Fig. 70. Pier with Wooden Piles and Reinforced Concrete Deck., 33rd St., Brooklyn, N. Y.

necessary to hold the transverse rows of piles straight during the construction of the decks.

The illustration shows the method of constructing the concrete deck. The slabs were cast in alternate bays 10 feet wide extending from side to side of the pier. It was intended to have the granolithic finish on the concrete act as the wearing surface, but it did not prove durable and the deck was covered with a $1\frac{1}{2}$-inch asphalt pavement.

Provision was made for carrying sewer boxes to the outer end of the pier, as shown in the illustrations.

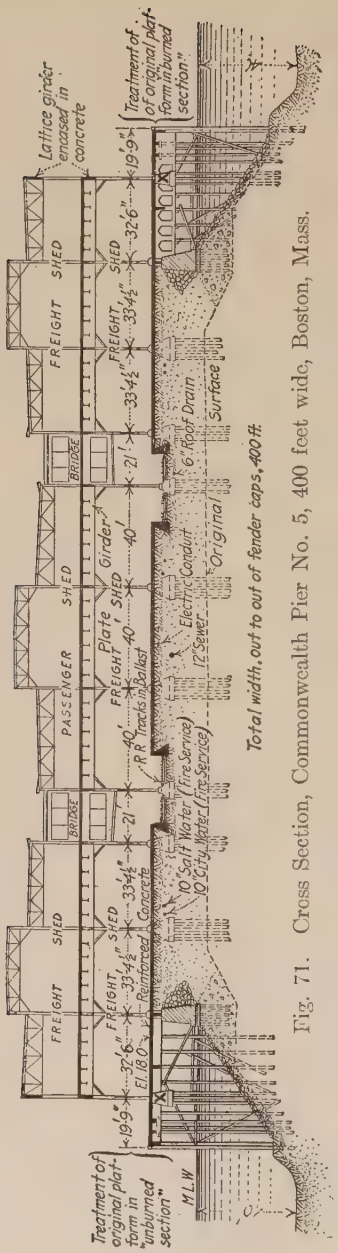

Fig. 71. Cross Section, Commonwealth Pier No. 5, 400 feet wide, Boston, Mass.

The pier carries a single-story steel shed with four rows of posts. The two outer rows of piles are spaced twelve feet apart and the deck over this portion consists of a concrete slab reinforced with wire mesh, supported on wooden planks resting on rangers built up of two 12-inch by 12-inch timbers placed one on top of the other.

Adjacent piers commenced within the last year have the wooden side caps restored, as it was found that their omission allowed lighters to float under the deck of the pier and rip it up when the tide rose or when there was a heavy swell.

A freight pier of this type for the Central Railroad of New Jersey at Communipaw is notable in that all the piles and lumber are creosoted to prevent decay and that the presence of rock under the sand and gravel of the bottom allowed a penetration of only 8 feet for the piles. To give the structure stability cribs extending from side to side of the pier and covering the space of four rows of piles were placed at the outer end and midway between that point and the bulkhead.

In Boston concrete caps and deck on wooden piles were

used in the reconstruction of Commonwealth Pier No. 5, shown in Figs. 71 and 72. This pier was built in 1900 and rebuilt in 1913, the wooden pile-caps and decks being replaced with concrete beams and slabs. Where a portion of the

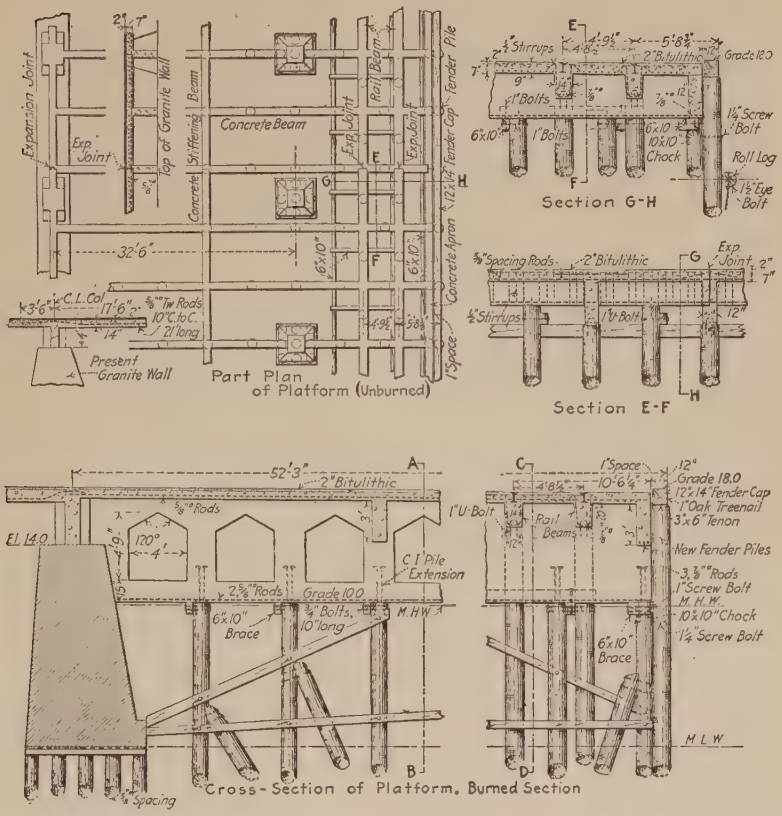

Fig. 72. Pile Platform with Wooden Piles and Reinforced Concrete Caps and Decks. Commonwealth Pier No. 5, Boston, Mass.

platform had been destroyed by fire the concrete beams were $7\frac{1}{2}$ feet deep and extended down practically to high water. A feature was the placing of cast-iron extension piles in the beams, so that the latter would be supported in case the lower portion should be disintegrated by frost and sea water.

Piers with Wooden Piles Cut off near Low Water. — The pier on wooden piles with the platform at low-water level with incombustible materials above has the advantage over the type in which the piles extend up to the deck, that no portion of the structure is subject to decay and that it is free from fire risk from cargo on deck, vessels alongside, or from burning oil, cotton bales, or similar articles floating under it.

When the platform supports a solid filling held in place by a masonry wall it has the disadvantage that the piles

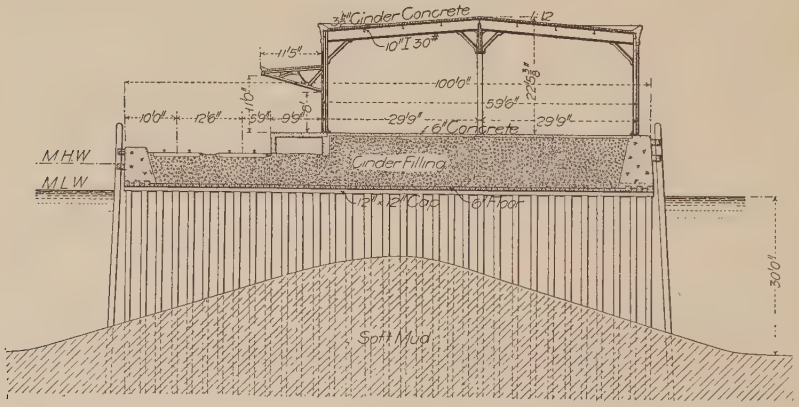

Fig. 73. Pier with Platform at Low Water Level on Wooden Piles, D. L. & W. R. R., Hoboken, N. J.

carry a heavy dead load and many more piles are required than in class 1 or in class 2, where the platform supports a concrete deck on posts.

This type is not suitable for waters in which the marine borers are active, even if the piles are creosoted, if a life of more than fifteen or twenty years is desired, as the nature of the structure above the platform renders the renewal of the piles practically impossible when the creosote is washed out and the piles are eaten away.

A pier of class 2a, 100 feet wide and 600 feet long, is shown in Fig. 73. In this case the pier was built by a railroad which had close at hand a large supply of cinders,

which afforded a cheap and light material for filling. The mud at this location was 185 feet deep and the piles were 85 feet to 95 feet long. They were driven 3 feet apart in transverse rows 5 feet apart and were designed for maximum loads of 12 tons. The depth of water at the sides of the pier varied from 20 to 30 feet.

Another pier near by has a portion of the piles in hard bottom and a portion entirely in mud. In this case the loading is varied from 17 to 12 tons, according to the nature of the bottom.

An example of type 2b is that adopted for some piers at the U. S. Navy Yard in Brooklyn, Fig. 74. In this case

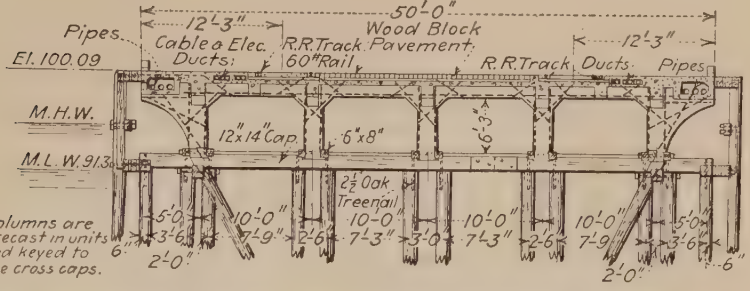

Fig. 74. Pier with Timber Piles supporting Reinforced Concrete Deck on Reinforced Concrete Posts, Navy Yard, Brooklyn, N. Y.

reinforced concrete columns with spreading tops were cast on shore and fastened to a timber platform on piles, located just above low water, by keys and wedges. A reinforced concrete deck was then laid on top of the columns. This method avoided all the uncertainties of concrete deposited in forms below high-water mark and subject to the action of the water before hardening, did not put a very heavy unit load on the supporting piles, and gained all the advantages of the low, platform type. Some criticism has been made, however, of the possible plane of weakness between the platform and the concrete structure which it supports.

In Philadelphia two piers, each 550 feet long and 180

feet wide, with wooden piles cut off just above low water and with concrete above have recently been built. One has cross walls of concrete supported on double rows of piles 20 feet apart and one has columns on groups of piles spaced 20 feet in each direction. The tidal range is about 6 feet and the concrete walls and columns were cast between tides. The two sections are shown in Fig. 75. These designs were selected from six on which bids were received. The other designs were for pile platform types 2a and 1b and solid-filled piers. The second of the chosen designs was the cheaper, but it was desired to give both a trial, as a number of similar piers was to be built.

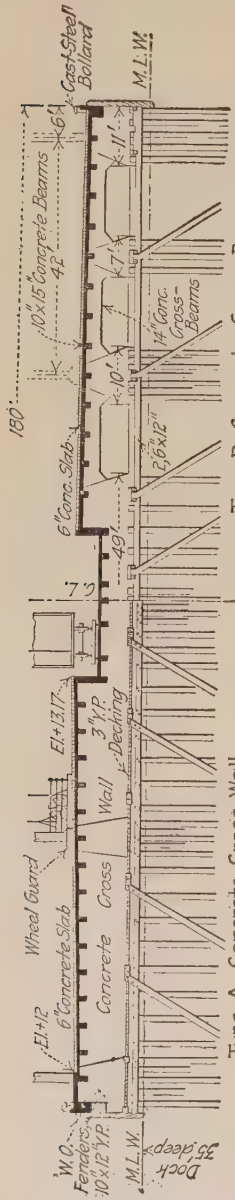

Fig. 75. Piers 38 & 40 with Reinforced Concrete Decks, Cross Walls and Posts on Wooden Piles, Philadelphia, Pa.

Piers on Composite Piles of Wood and Concrete. — Two large steamship piers have been built in the tropics on wooden piles protected with concrete, one at Bocas del Toro, Panama, and one at Port au Prince, Haiti.

The pier at Bocas del Toro is shown in Fig. 77.[1] It was built parallel to the shore on a shelving bottom, where the water was 10 feet deep on one edge of the structure and 22 feet on the outshore side. The tidal range was only 9 inches and the locality was free from ocean swells. Untreated wooden

[1] T. H. Barnes "The Reinforced Concrete Wharf of the United Fruit Company at Bocas del Toro, Panama." Trans. Am. Soc. C. E., Vol. LXXI, p. 295.

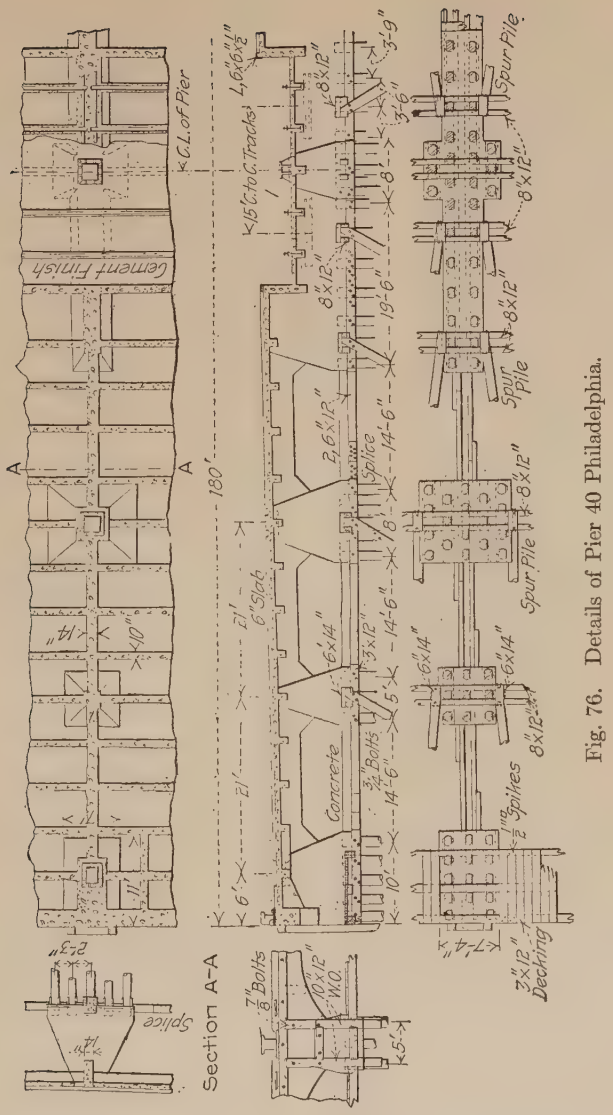

Fig. 76. Details of Pier 40 Philadelphia.

piles were driven ten feet apart in both directions, with an average penetration of 40 feet, and over them were placed, by a floating pile-driver, tapering, conical, reinforced concrete shells, extending from below the mud

line to above high water. These shells are 2 inches thick, 20 inches in diameter inside at the top, and 16 inches at the bottom. The space between the pile and the shell was sealed with concrete deposited through the water, the water pumped out, and the remaining space filled with lean concrete to within 5 feet of the top of the shell. Reinforcement for the columns which extended from the tops of the shells to the pile caps was then put in place, the shells

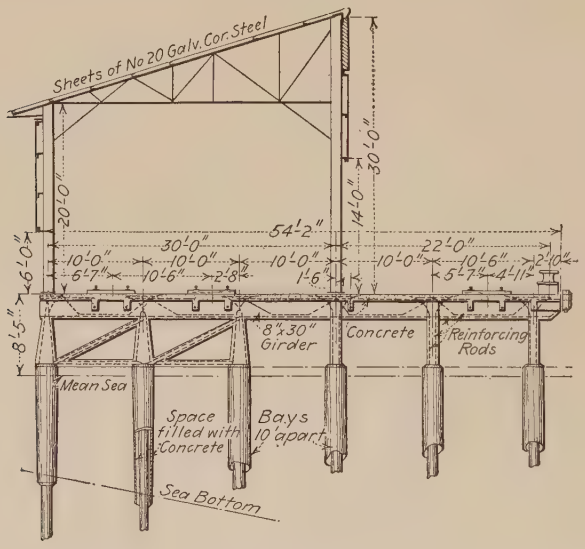

Fig. 77. Pier with Composite Piles and Reinforced Concrete Deck, Bocas Del Roro, Panama.

filled to the tops, and the whole protected pile straightened and stay-lathed. Forms supported by steel rails which rested on the tops of the shells were then built for the reinforced concrete columns, beams, braces and slabs, and the concrete portion of the structure completed.

One of the most difficult points in the design of nearly all concrete piers is the transverse bracing, and a notable feature of this pier is the use of horizontal and diagonal braces of reinforced concrete. These were successfully constructed, though with some difficulty. The horizontal

braces were placed at about mean high water and the diagonals had a rise of about $4\frac{1}{2}$ feet, the deck being about $8\frac{1}{2}$ feet above mean tide.

The shells were reinforced with electrically welded wire fabric with a 6-inch square mesh. They were from 16 to 30 feet long and were made at the rate of about six in a day.

It was estimated that the pier cost about as much as one built of creosoted piles with creosoted timber beams and deck, but that it would last much longer, as the life of such piles was considered to be only 15 years. Various designs for concrete piles were considered, but were discarded, as

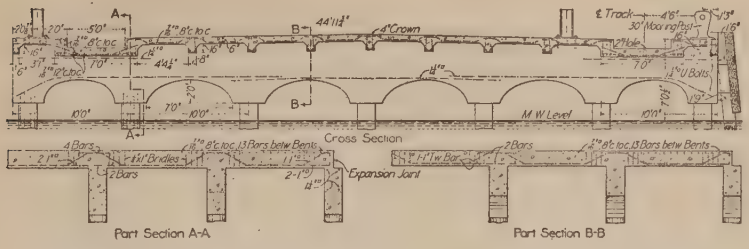

Fig. 78. Pier with Composite Piles and Reinforced Concrete Deck, Port au Prince, Haiti.

the length of 70 feet, which was required, was unprecedented in 1906, when this pier was built.

Only a small plant was required consisting of a floating pile-driver in addition to the stone crusher and concrete mixer.

The slab is 7 inches thick and calculated for 250 pounds live load.

Test piles were driven and loaded to determine the bearing power.

A pier of similar construction was completed at San Francisco in 1913. It was 800 feet long and 126 feet wide. The pile caps were of steel encased in concrete and carried wooden stringers and a plank deck.

A pier at Port au Prince, Haiti, was built in 1912 on timber piles protected by encasing them, before driving,

with wire mesh and cement mortar. The pier is 825 feet long and from 50 to 60 feet wide, and is located in water with a minimum depth of 27 feet. The design is shown in Fig. 78 and the method of constructing the pile in Fig. 79. The piles had a maximum length of 57 feet and the penetration varied from 15 to 30 feet. The protective coating on the piles reached from the tops to within 5 feet of the points. They were spaced 10 feet apart each way, and were capped with reinforced concrete girders 18 inches wide and 5 feet 6 inches deep, arched between the piles, supporting longitudinal beams and a 5 to 7 inch slab. The

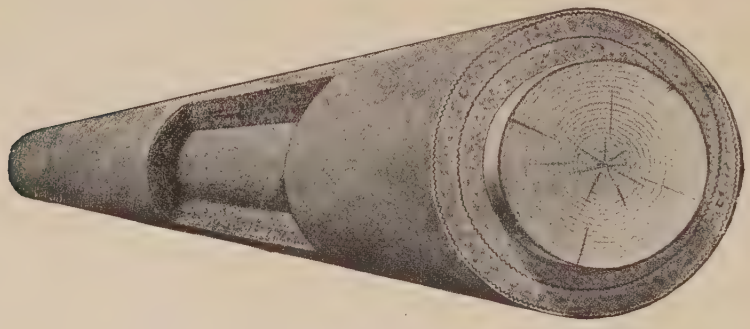

Fig. 79. Composite Pile, Port au Prince, Haiti.

forms for the superstructure were supported by means of wooden collars clamped to the piles.

Piles of somewhat similar construction, in which the mortar was applied by the cement gun, were used in constructing a bulkhead wall at San Juan, Porto Rico, in 1913. These piles were driven to a 20-ton bearing with a 3000-pound drop hammer without damage to the protective coating.

Piers on Metal Piles or Cylinders. — Before the advent of reinforced concrete, piers on piles or large cylinders of cast iron, wrought iron, or steel were built in many places where marine borers were active. Some have withstood corrosion very well and have lasted for 30 years or more and some, notably those built on piles made of steel pipes,

for steamboat landings on the ocean shore, have lasted only 10 years before they needed extensive repairs.

One of the earlier piers of this design was built at Fortress Monroe, Va., thirty-two years ago. This pier was designed for a steamboat landing and is in a location exposed to strong winds and currents and at times a heavy sea. The piles were of cast iron, one inch thick, and where there was a firm bottom, had a disc on the lower end and were jetted into place. In a portion of the pier where there was a layer of mud overlaid with sand, creosoted wooden piles were first driven and cut off above the bottom; cast-iron screw piles were then forced down over them. All the iron piles were pumped out and filled with concrete. A platform of creosoted piles with wooden deck was built around the portion of the pier at which the steamboats landed, as the iron structure was thought to be too lacking in elasticity for boats to lie alongside it. Recent reports state that the cast-iron piles are in as good condition as when put in place, but that the beams of the deck are badly corroded, the scale being $\frac{1}{2}$ inch or more in thickness.

An iron coal pier was built at Lamberts Point, Norfolk, Va., in 1892 which carried an elevated steel railroad structure for loading coal. The piles were of commercial tubing 12 inches in diameter and $\frac{1}{2}$ inch thick, 45 to 57 feet long, and were filled with concrete. They were fitted with discs 4 feet in diameter and were jetted into place in a sand bottom. The jetting was aided by pulling down on the piles and each pile was weighted to bring it to a firm bearing. The iron piles were surrounded by a braced fendering of creosoted piles. Iron cross bracing, extending considerably below the low-water line, was used to give lateral strength.

An ocean pier for a steamboat landing was built in 1879 at Coney Island, N. Y., of wrought iron tubular piles about 57 feet long and $8\frac{5}{8}$ inches in the outside diameter and $\frac{1}{2}$ inch thick. They were fitted with cast-iron discs and were sunk from 12 to 15 feet into a sand bottom. This pier had two decks 12 and 24 feet above high water and the piles

were cross braced between the water and the lower deck. Another pier of somewhat similar construction was built at the same place several years later.

Another example of a tubular steel pile pier is that built in the open ocean for a steamboat landing at Atlantic City, N. J., in 1897–1898. The piles were $10\frac{3}{4}$ inches in outside diameter and $\frac{3}{8}$ of an inch thick and the caps were of plate-girder construction. In 1905 the piles and particularly the girders had rusted so that they were reduced in section by from $\frac{1}{5}$ to $\frac{1}{3}$. The pier was entirely rebuilt by encasing the piles and beams in reinforced concrete designed to take the entire load independent of the remaining strength of the original structure.

Another similar pier was built at Old Orchard Beach, Me.

Many piers have been built with iron or steel cylindrical columns filled with concrete, both plain and reinforced.

A wharf of this type was built at Tampico, Mexico, in 1900, for the shipment of petroleum, to replace one of creosoted timber which had been burned to the water line. The bottom at the site of the wharf was formed of fine sand about 50 feet below the water level overlaid with silt. The cylinders were about 50 feet long and 6 feet in diameter of $\frac{1}{2}$-inch steel plate, except the portions above water, which were $\frac{5}{8}$ inches thick. Most of the cylinders were sunk by pulling down with jacks attached to the old piles and by driving with a light hammer, but some were sunk by the pneumatic process. Piles were driven inside the cylinders by means of a 30-foot follower, and extended into the sand. The mud and water were removed from the cylinder and they were filled with concrete, the portion required for sealing being placed by means of a tremie. They were spaced about 20 feet apart each way and were calculated to carry from 116 to 235 tons each. The deck was of steel beams supporting a concrete arched flooring designed for a live load of 800 pounds per square foot. The two upper sections of some of the cylinders were galvanized and the piles were creosoted. The purpose of

creosoting the piles, which were entirely protected by the concrete, silt, and water from rot and borers is not apparent. The design is well shown in Fig. 80.

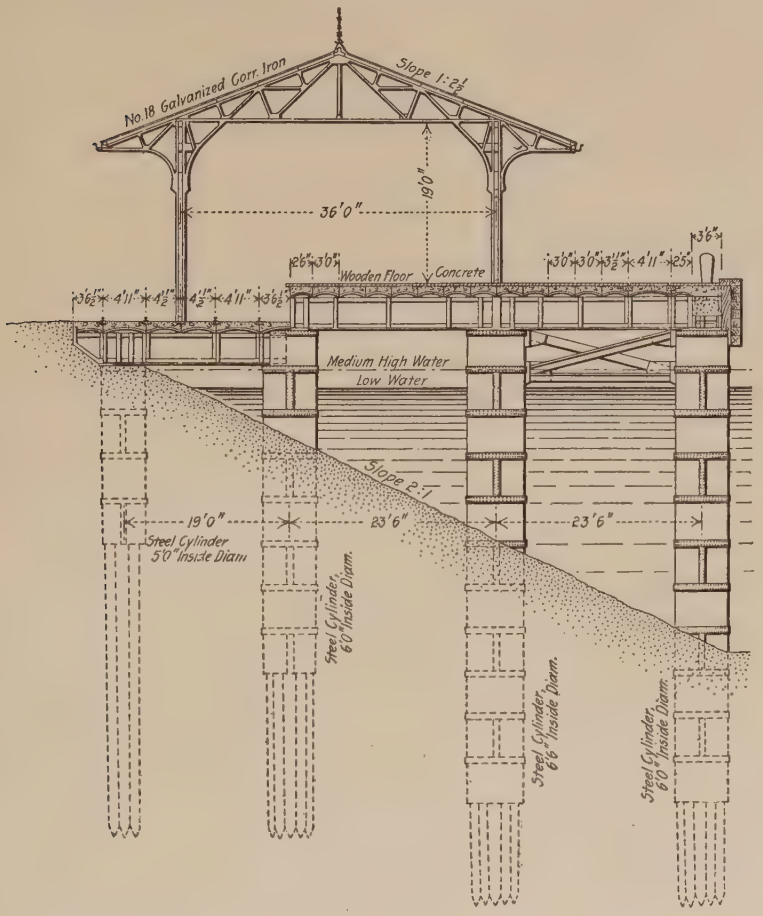

Fig. 80. Wharf with Steel Cylinders, Tampico, Mexico.

Two piers of similar construction, one of which was 70 feet wide and 600 feet long, were built in Manila in 1906. The columns were spaced 20 by 25 feet. They rest on clusters of piles cut off at various heights. The steel shells were placed over the piles, the mud and water pumped out,

the bottom sealed with concrete, reinforcement placed, and the shells filled with concrete. The columns were capped with plate girders carrying steel beams and a reinforced concrete slab with a wood block pavement at 10 feet 5 inches above mean low water. The steel cylinders were very thin in these piers and the concrete which filled them was heavily reinforced. Such cylinders act merely as forms for the concrete above the bottom, as they soon rust away. The cylinders were braced with diagonal rods of steel.

Another huge coal pier was recently completed at Lamberts Point, Norfolk, Va., in which the steel superstructure which carried the railroad tracks was supported on steel cylinders 41 feet high and 18 feet in diameter filled with concrete resting on piles which were driven by means of a follower and telescopic leads to 27 feet below low water. The concrete was not reinforced. A protective structure of timber with creosoted piling was built around the cylinders to provide wharfage for vessels.

A pier with cast-iron cylinders 30 inches in diameter and $1\frac{3}{8}$ inches thick was built at Cienfuegos, Cuba, in 1906. The cylinders weighed 420 pounds per linear foot and carried a load of 50 tons each. They were braced with 2-inch square steel rods. The deck beams were steel-plate girders and the deck was of reinforced concrete.

One of the first ventures in the use of reinforced concrete piles for large steamship piers is found in those built by the Atlantic and Birmingham Railway at Brunswick, Ga., which were completed in 1907. Two piers were built 140 feet wide, one 350 and one 750 feet long, and the method of construction is shown in Fig. 81. The superstructure was entirely of wood. The piles are rectangular, 10 inches by 16 inches in section and from 32 to 50 feet long, and were driven by jetting through a centrally located pipe. The deck of the pier is 7 feet above high water and 14 feet above low water. The piles were capped with double timbers resting one on each side on shoulders in the piles. The caps carry 6-inch by 14-inch wooden joists notched down on

them and fastened with drift bolts, and a 3-inch plank deck was laid on the joists. Horizontal braces of creosoted 6-inch by 10-inch lumber were bolted to the piles just above low water and four rows of inclined braces were placed between the horizontal braces and the caps. In order to make the sides of the piers elastic, so as not to injure vessels lying alongside, the outside row of bearing piles on each side was of creosoted timber braced with inclined piles and protected by fender piles of the same material. The pier sheds did not project beyond the concrete piles, so that the wooden piles could be renewed without making holes in the roof of the shed. One of these piers was rammed by a steamer during the construction, without serious damage to the structure.

A similar pier was built at the U. S. Navy Yard at Charleston, S. C.

In reconstructing the steel pier on the ocean

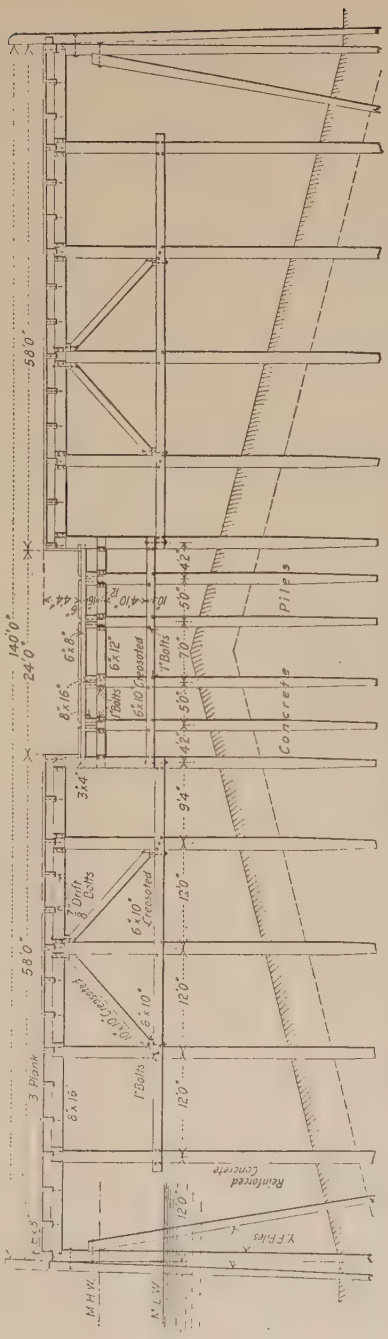

Fig. 81. Pier with Reinforced Concrete Piles and Timber Caps, Bracing and Decks, Brunswick, Ga.

shore at Atlantic City in 1906 additions were made with reinforced concrete piles. A portion of them were of 12 inches diameter with a maximum length of 32 feet 6 inches, driven 8 to 14 feet into the sand, and part were 25 inches in diameter with a maximum length of 52 feet and a penetration of 16 feet. The 12-inch piles were cast on end complete with knee braces at the upper end. The 25-inch piles had the lower 12-feet first cast in one piece. A watertight form of galvanized steel or of wood, long enough to reach above the water when the pile was in place, was then attached to the 12-foot section, which with the concrete form was then jetted down to the required depth and the form filled with concrete. Both the steel and wooden forms were left on the piles. The piles had enlarged bulbs on the lower ends, 30 inches and 42 inches in diameter respectively, to give additional bearing power.

The original steel piles were encased in a reinforced concrete jacket with a wooden outer form and a sheet-steel inner form. These jackets were cast above water in section of convenient length, as they were sunk by water jets to the discs at the lower end of the steel piles. The space between the concrete jacket and the steel pile was filled with concrete. The details of the 25-inch new piles are shown in Fig. 82.

A pier in which piles of somewhat similar construction were used was built to serve as a recreation pier and to carry a sewer outfall pipe at Santa Monica, Cal., in 1908. It was 1600 feet long and 35 feet 8 inches wide, 24 feet above mean low water, and the depth of water at the outer end was 25 feet. There were three piles in a bent and the bents were 20 feet apart. The piles were 14, 18, and 23 inches in diameter and had a 30-inch bulb at the lower end. They were about 70 feet long at the outer end of the pier. They were driven by the water jet, a pipe being cast for the purpose in the axis of each pile. The 14-inch piles on a portion of this pier were jacketed with a steel cylinder 22 inches in diameter, made of No. 10 plate from 2 feet above high water to 2 feet 6 inches below the ground line,

the space between the jacket and the pile being filled with concrete. The piles in the outer portion of the pier were not jacketed, as it was found that they were covered with a heavy protecting growth of mollusks soon after they were driven. There were three rows of beams of 9-inch by 18-inch reinforced concrete between the bents to give longitudinal stiffness. The pile caps of 9-inch by 30-inch reinforced concrete carried 4-inch by 16-inch by 22-feet fir joists spaced 30 inches apart and stiffened by 2 rows of 2 by 4 bridging in each bent. On the joists were laid 2-inch plank and a 3-inch concrete slab.

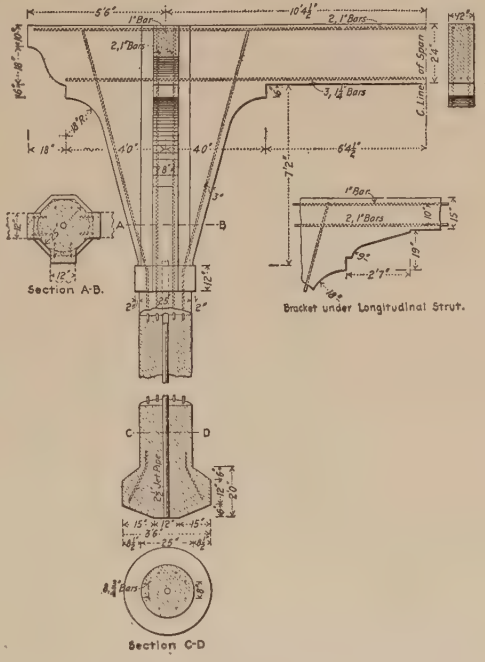

Fig. 82. Ocean Pier with Reinforced Concrete Piles, Atlantic City, N. J.

Another ocean pier was built on reinforced concret piles at Long Branch, N. J., in 1912. The piles were hollow, 22 inches square outside, with a circular hole in them 13 inches in diameter. They were from 45 to 68 feet long and were driven into the sand, clay, and gravel bottom about 22 feet by means of four water jets. A 150 H. P. pump was required. The deck of the pier was 22 feet above low water and the outer portion of the pier, which was intended for a landing place for steamboats, was braced with inclined piles. The shell of the hollow piles was of 1: $1\frac{1}{2}$: 3 concrete and the interior portion was filled with a leaner mixture. The hollow section of the piles provided

a convenient means of splicing those which were too short to reach the hard gravel layer to which it was desired to drive them or which could not be economically handled if made of the required length in one piece, rods being placed in the core to strengthen the joint. Piles made with this

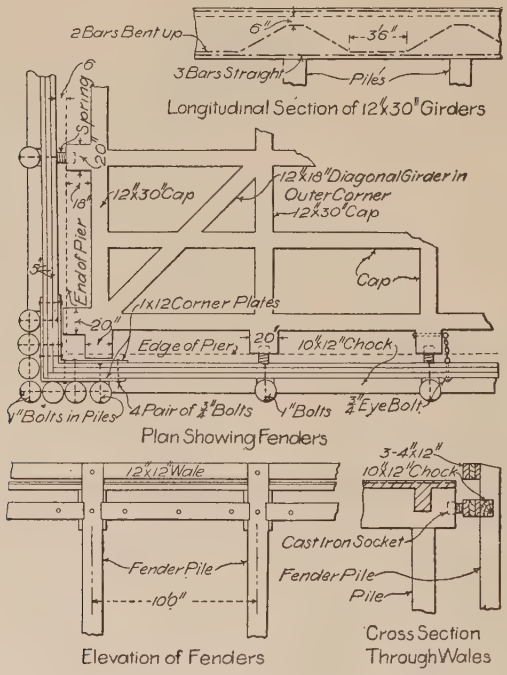

Fig. 83. Reinforced Concrete Pile Pier, Oakland, Cal.

rich mixture have proved durable in this locality, while those of 1: 2: 4 concrete have been badly abraded by the sand on the beach between high and low water. The caps, joists, and deck of this pier were of reinforced concrete.

Another pier, one of the first large piers entirely of concrete, 295 feet long by 124 feet wide, was built at Oakland, Cal., in 1911 and is illustrated in Fig. 83. The piles were octagonal, 16 inches in their short diameter and from 30 to 50 feet long. Driving the piles with a hammer in

the clay and tightly packed gravel of the bottom fractured the heads and they were put in place by jetting and "churning" or "spudding." Horizontal bracing was provided by putting in three concrete brace walls reaching from the deck to the water, extending about 21 feet each side of the centre line of the pier. The deck system is of reinforced concrete girders and beams supporting a 4-inch reinforced concrete slab with a 2-inch asphalt pavement. Fenders are of the timber and car-spring type and the mooring piles are of timber driven through holes in the deck. All timber was creosoted. Concrete of 1: $1\frac{1}{2}$: 3 mixture was used for the upper five feet of the piles and 1: 2: 4 for the balance.

The piles were spaced about 10 feet in each direction.

Three notable steamship piers have recently been built on reinforced concrete piles of great length, one at Halifax, N. S., where the climatic conditions are most severe, and two at Havana, where the conditions in a tropical climate and a sheltered harbor are most favorable for the durability of the concrete. In the Halifax pier the piles were placed in rows and carried the deck on the ordinary girder and beam construction, but at Havana they were driven in clusters and the deck slab was carried on shallow beams between rectangular pile caps. At Halifax inclined piles were used throughout the pier to give lateral stiffness, but at Havana bracing piles were used only in the two outer rows of pile clusters, as it was not considered that they would give sufficient stiffness in addition to that afforded by the piles, the weight of the structure with its two-story concrete shed, and the connections between the piles and caps, to pay for their extra cost. For the construction of the Halifax piers an enormous combined floating pile-driver and derrick was built, but at Havana the piles were placed with a floating derrick and driven by a steam hammer resting on and fastened to the heads of the piles. Piles were chosen for the Havana design instead of the large columns such as are used on the Pacific Coast because they

were considered the cheaper on account of the length of the columns required.

A notable difference between the two designs was that while both piers had to carry two-story sheds, the Halifax pier was calculated to carry a live load of 1000 pounds on the first floor and 500 on the second and 110 on the roof, and those at Havana, only 250 and 400 pounds respectively,

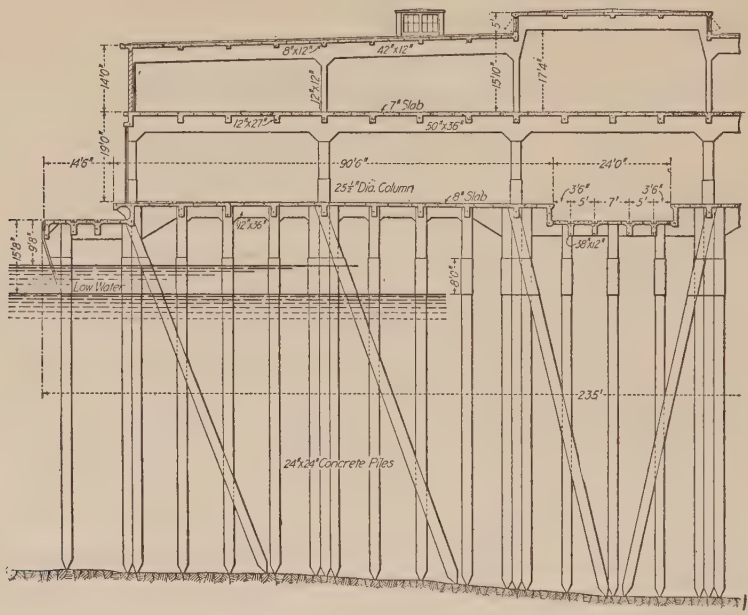

Fig. 84. Reinforced Concrete Pile Pier, Halifax, N. S.

and none on the roof. At both places large yards and considerable plant were necessary for fabricating the piles, handling them in the yard, and transferring them to the piers.

The Halifax pier is shown in Fig. 84. This pier is one of four to be built in the inner harbor. It is 693 feet long and 235 feet wide, located in water 60 to 70 feet deep, on a rock bottom, 61 to 87 feet below the pier floor, overlaid by from 5 to 12 feet of clay and hard pan and with 30 feet of soft mud at the shore, and 5 feet at the outer end. The

mean range of tide is about 6 feet and the height of the deck is 14 feet 2 inches above extreme low water.

Special precautions were taken to make the concrete durable under the extreme conditions of service. The alumina in the cement was limited to 6.3%, to reduce the chemical action of the sea water on the cement; the proportion for all concrete below high water was made 1: $1\frac{1}{2}$: 3 to resist the absorption of water by the concrete and all concrete surfaces were sheathed from low water to 2 feet above high water with two layers of creosoted 2-inch plank to prevent freezing and erosion by waves, ice, and driftwood. The piles were designed to carry 100 tons, including their own weight in water. They are 24 inches square, 55 to 77 feet long, and weigh from 12 to 23 tons. The bracing piles were cast with a camber to compensate for the bending of the piles under their own weight. A 12-ton steam pile hammer, especially built for these piers, was used. The piles are spaced 10 feet apart in the bents and the bents are 18 feet apart longitudinally. There are six rows of shed columns and under each column there is a bracing pile and one or two extra vertical piles, making 33 vertical and 6 inched piles in each bent. The upper portion of the piles was cast after the piles were driven. They were capped with girders 36 inches deep, carrying beams 24 inches deep and an 8-inch deck slab.

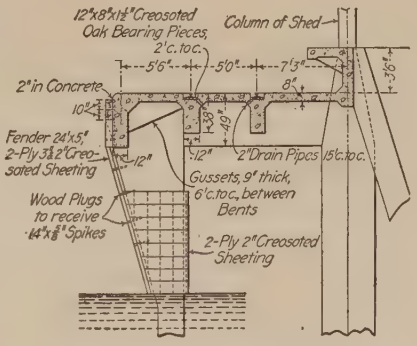

Fig. 85. Side Detail, Halifax Pier.

Especial attention was given to transverse stiffness, owing to the great unsupported length of the piles. The vertical piles were stiffened by a bank of dredged material deposited around them and by the inclined piles.

The Havana piers are 164 feet wide and 660 and 680

feet long and are located in water from 12 to 40 feet deep, on a bottom consisting of 15 to 20 feet of soft mud overlying sand or clay. The range of tide is only 18 inches and the deck was elevated only 5 feet 3 inches above mean low water to have it conform to the level of the marginal street. The two-story concrete sheds are carried on columns spaced about 20 by 30 feet apart.

The extraordinarily low elevation of the deck required for these piers presented peculiar difficulties in the design, and the problem was solved by supporting the deck slab

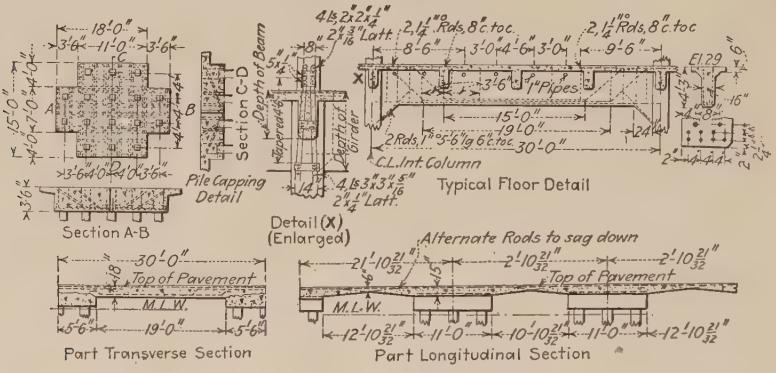

Fig. 86. Reinforced Concrete Pile Piers, Havana, Cuba.

on wide shallow beams carried on clusters of piles located under the shed columns. The clusters contained from four to eighteen piles and were capped with reinforced concrete $3\frac{1}{2}$ feet thick, including the thickness of the slab. The caps measured from 7 by $8\frac{1}{2}$ feet to 20 by 24 feet in area. The longitudinal beams were 15 and 18 inches thick and 11 feet wide supported on recesses in the sides of the caps and the transverse beams were cantilevers 7 feet wide. The deck slab averaged 12 inches in thickness. Fig. 86 shows typical pile clusters and sections. In Havana Harbor there is little or no current and the close spacing of the piles and pile clusters was unobjectionable. The piles were 16, 18, and 20 inches square and from 45 to 85 feet in length, with a maximum weight of 17 tons. A notable

feature was that they were reinforced for bending stresses in one plane only, in order to reduce the amount of steel to a minimum. Pipes were cast in the concrete at the proper places for attaching the lifting ropes, and the piles were kept with the proper side uppermost until they were raised to the vertical position. Driving the piles with a water jet proved unsuccessful and they were driven with a six-ton steam hammer at the rate of about ten in a day. Fifteen tons dead load and 25 tons live load were allowed on a pile and the bearing power was determined by loading numerous test piles.

Another large pier on concrete piles in San Francisco was begun in 1914. It is 975 feet long on one side and 817 on the other and 200 feet wide. The depth of water is from 41 to 57 feet. The most notable feature of this pier is the extraordinary length of the piles, which have a maximum of 106 feet in the outer rows. They are 16, 18, and 20 inches square and were designed for a load of 40 tons in addition to their own weight. The penetration was about 35 feet, ten of which was in soft material.

Piers on Reinforced Concrete Columns. — The columns in use on the Pacific Coast have been developed to the present successful form through several stages. The design grew partly from a method of protecting wooden piles which was considerably used, and partly from the steel cylinders filled with concrete previously described. The method of pile protection consisted of placing a wood-stave pipe around a pile after it had been driven and filling the space between the pile and the pipe with concrete. The concrete deposited in this manner in many cases, often due to depositing the concrete in water, was imperfect and allowed the teredo to get at the piles, but where the forms were carefully pumped out and the concrete reinforced, success was obtained. In some cases such protected piles failed because the mud line was lowered below the bottom of the casing by dredging subsequent to the completion of the structure.

The first step was to use a wood-stave cylinder of about $3\frac{1}{2}$ feet in diameter. As it was found that a column of a diameter sufficient to carry the vertical load did not have sufficient area to give the required bearing on the bottom, the foot of the pile or column was enlarged to 7 or 8 feet in diameter. The method of construction was as follows: a wood-stave pipe with a cast-iron bell bolted to the lower end was jetted and hammered down through the mud into the hard bottom. The water, mud, and sand were then removed from the interior, the bottom sealed with concrete, the reinforcement placed, and the cylinder filled to the top with concrete. The wooden form was left in place. A pier in which the concrete for the columns was deposited through the water was destroyed, owing to the disintegration of the imperfect concrete.

The next step in the development was by the use of open, cylindrical steel cofferdams in which the columns were built. Some of these were $7\frac{1}{2}$ feet in diameter and 60 feet long, weighing about 20 tons. They were driven by floating pile-drivers, or land leads of enormous size and strength supported on temporary pile trestles. These machines were used to operate the bucket for excavating the sand and mud from the cylinders and for pulling up the cylinders after the columns were cast, also for operating swinging leads which were lowered into the cylinders for driving wooden foundation piles, which were necessary where the bottom did not have sufficient supporting power without them. The cylinders were pumped out and the wooden forms built in them. The concrete was deposited by means of chutes, and was tamped into place by a man inside the forms. The steel cylinders were then withdrawn, the forms being left in place on the concrete columns. Some difficulty was found in keeping these cylinders plumb if the mud for any cause moved while they were in place, and the concrete columns had to be braced to neighboring columns as soon as the steel cylinders were removed.

In some cases it has been found impossible from various

causes to seal the steel cylinder. This difficulty was overcome by putting a wooden bottom in the form and suspending it above the water in the pile-driver leads, hoisting the concrete to the top of the form and lowering the completed column down through the steel cylinder. In another case the bottom of the steel cylinder was made detachable, filled with concrete to make a seal, and left in place when the upper portion of the cylinder was raised.

In comparing the pier built on concrete piles with that built on columns, the advantage of one over the other, aside from the cost, which may be favorable to either plan, depending on the local conditions, is in the matter of bracing. The columns cannot conveniently be braced against horizontal forces except by shallow knees between the heads of the columns and the deck beams, or by steel braces fixed to collars fastened to the columns, which are subject to conditions which produce a maximum amount of corrosion. Such piers depend on their weight, the stiffness of the columns, and the shallow knee braces to resist the thrust. On the other hand, where the concrete piles are used bracing piles can be driven and the direct resistance of the bottom utilized. Both these types require floating derricks of large capacity, or huge pile-drivers, or both, for handling the piles or the steel cylinders in which the columns are built.

While the column method has been used in building several large piers in San Francisco, it is doubtful if it is as economical as concrete piles where the nature of the bottom is such that piles can be driven. Three great piers have been built during the last five years on the Atlantic, one at Halifax on rock at great depth and two at Havana on soft bottom, and the latest pier designed for San Francisco is now being built on concrete piles some of which are of unprecedented length.

An early example of the type of pier built on concrete columns is shown in Fig. 87. Two piers Nos. 38 and 40 were built on this plan. In these piers the concrete columns

were cast in a wooden form with an enlarged cast-iron bottom section, driven by jets and hammered into the impervious clay overlying the rock, and pumped out before the concrete was put in. The depth of the clay was about 40 feet below the water. These piers were about 130 feet by 650 feet and the cylinders were spaced 15 feet each way. The columns carried steel cross-girders and longitudinal

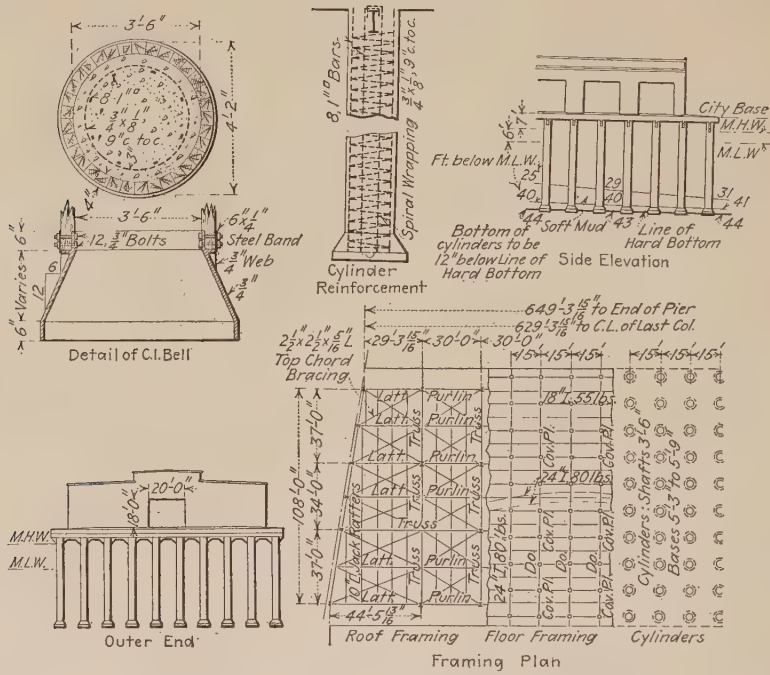

Fig. 87. Pier on Reinforced Concrete Columns, San Francisco, Cal.

beams encased in concrete which supported a reinforced concrete slab and asphalt and brick pavements. They carried single-story sheds built with steel frames and concrete walls and roofs.

Later piers were constructed with columns built in steel cofferdams similar to those at Ft. Mason, and the caps and joists were of reinforced concrete instead of steel. A floating pile-driver with 118-foot leads was used, also one 90 feet high supported on falsework.

The three piers at Ft. Mason, in the construction of which cylindrical steel cofferdams referred to above were first used, are 500 feet long and 81, 118, and 81 feet wide. They are in a locality where heavy ground swells, swift currents, and strong winds rendered the use of floating equipment impracticable and made the work especially difficult and costly. The water was 25 feet deep at the outer end of the pier and the depth provided alongside was 31 feet. The bottom consisted of layers of sand and mud to a depth of from 70 to 90 feet. The columns were spaced $18\frac{1}{2}$ feet each way and were capped with steel beams encased in concrete carrying a reinforced concrete slab supported on beams similar to the pile caps. The columns were 4 feet in diameter above the bell at the bottom and were cast in wooden forms which were built in open steel cylindrical cofferdams. The latter were placed and removed by means of very large pile-driver leads 86 feet high, supported on a temporary pile falsework. Each column rested on 7 timber piles 60 to 85 feet long driven from 20 to 70 feet below the dredging line, and cut off about 11 feet above it. They were driven by means of a follower in a steel guide tube 40 feet long which was accurately located by means of a template and removed after the pile was driven. The steel cofferdams were used after attempts to place the forms without them had been found very difficult. They were 8 feet in diameter and weighed 17 tons. The pile-drivers had a lifting capacity of 100 tons to provide the necessary power for pulling the cofferdams out of the mud. The concrete in the columns was mixed in the proportion of $1 : 1\frac{1}{2} : 3$.

A pier was built on similar principles to those of the two preceding examples at the Navy Yard at Charleston, S. C., in 1915 in which was introduced a novel feature which permitted the inspection of the concrete in the columns. The lower portion of the steel cofferdam 5 feet long was fastened to the upper portion by means of bolts. The enlarged concrete footing surrounding the wooden piles

was cast in the steel cylinder as a form. Steel forms for the column were then set on the concrete footing and the column poured. The forms were then stripped, the concrete inspected, and the bolts holding the two parts of the cylinder taken out and the upper portion of the cylinder removed, the necessity of heavy lifting devices for pulling the cylinders out of the mud being thus done away with, a 25-ton floating derrick being sufficient. The cofferdam cylinders were from 42 to 52 feet long and 8 feet in diameter. The 45-foot piles were driven with extension leads and a 40-foot follower.

Several piers have been built with the decks supported on concrete columns in which thin shells of reinforced concrete, cast on shore, have been used in place of the wooden forms described above. These had the advantage that it was possible to inspect the surface of the concrete exposed to the action of the water and to reject any portion that was imperfect.

One of two built at Olongapo, P. I., in 1910 is illustrated in Fig. 88. It is 332 feet long by 45 feet wide and is located parallel with the shore with the outer edge in 25 feet of water. The cylindrical shells are 30 inches in diameter, $2\frac{1}{2}$ to 3 inches thick, with an enlarged lower portion to enclose the wooden piles which support them. They are from 25 to 30 feet long. The concrete deck slab was supported on steel girders and beams encased in concrete.

The construction of the shells was accomplished without the use of a core-form by using a sheet of wire cloth with $2\frac{1}{2}$ meshes to the inch fastened to the inside of the reinforcing hoops. The wire cylinder was then placed inside a wooden exterior mould in a horizontal position. Mortar was then poured into the mould and protruded through the wire cloth just enough to make a key. No interior form was required and a man smoothed the mortar on the inside of the wire with a trowel. The shells were driven from 2 to 4 feet into the sand bottom by water jets, and stay-lathed. A concrete seal was then put in place by bottom dumping

buckets, the shells pumped out, and the interior of the cylinders filled with concrete. These piers were braced transversely with diagonal steel rods placed by divers.

A similar pier was built at Puget Sound Navy Yard in 1912. Metal lath of the form known by the trade name of "Hy-rib" was used for the shell of the shaft and $\frac{1}{2}$-inch square wire mesh for the enlarged bottom portion. The Hy-rib was plastered with mortar and the balance of the

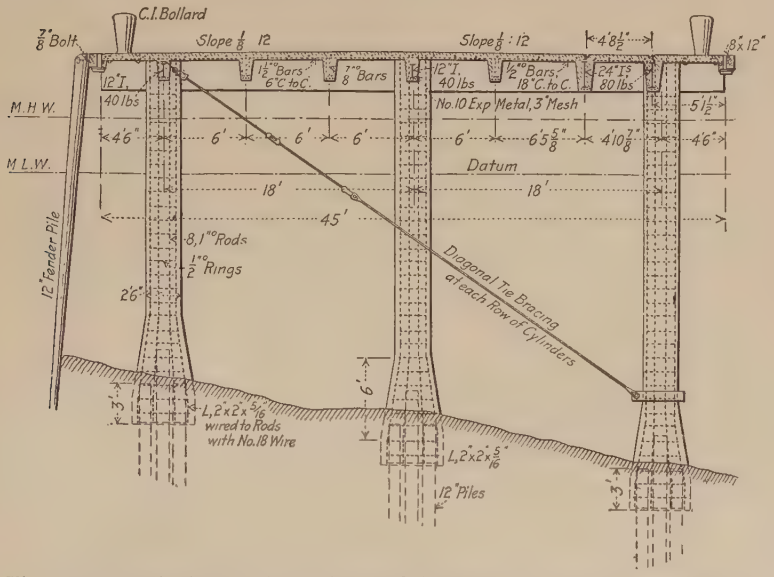

Fig. 88. Marginal Pier with Reinforced Concrete Columns, Olongapo, P. I.

shell was made of very wet mortar poured into the forms. Trenches were dredged for the shells, as the bottom was so full of old piles, boulders, and hard gravel that the use of the water jet was impracticable. The longest cylinder was 39 feet in length. Diagonal braces of steel rods were used to give transverse strength to the pier, which was only 60 feet wide. No piles were used under the columns. The specification allowed alternate bids on the method of constructing the cylinders in steel cofferdams or wooden shells and the above was chosen in preference to them.

An interesting method of construction of a pier or wharf on concrete columns is shown in Fig. 89, which illustrates a marginal wharf platform at Iloilo, P. I. In this case the cluster of piles was surrounded with a steel shell drum forced down into the bottom. The earth around the tops of the piles was then removed by a diver and concrete deposited in the drum to within 6 inches of the tops of the piles by means of a canvas bag. The drum was then

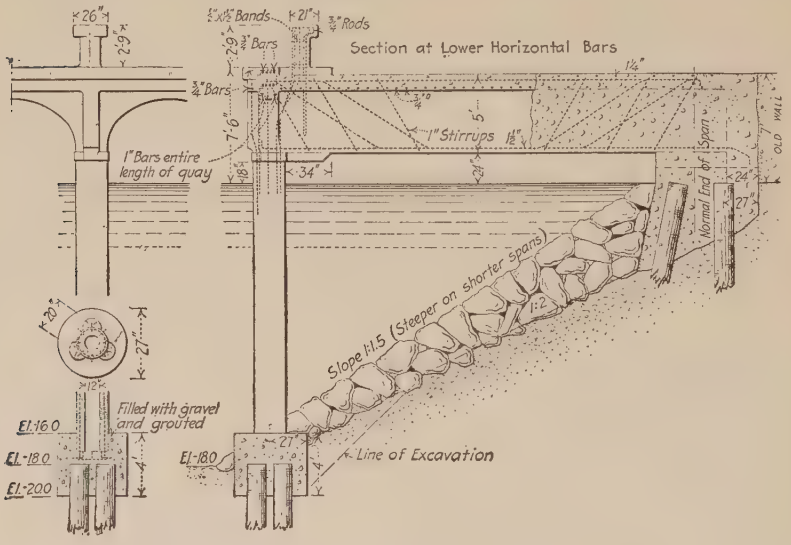

Fig. 89. Wharf Platform on Concrete Columns, Iloilo, P. I.

filled to the top with gravel and the concrete columns, which were cast on shore, set up in the gravel. Grout was next forced into the gravel through a one-inch pipe with a funnel on its top. The columns were hollow and when pumped out did not leak and showed that the grouting was perfect. Philipino divers on this work were paid only $1.00 a day.

At Balboa, Panama, a concrete marginal wharf, 708 feet long and 55 feet wide, was built in 1911 on large cylindrical, reinforced concrete columns driven to rock at a depth of 60 to 70 feet and spaced 35 by 30 feet. This wharf was

built in a tidal inlet which was cut off by a cofferdam and the construction carried on in the dry. After trying various methods it was decided to cast the cylinders in 6-foot lengths and handle them by means of a locomotive crane. The lower section was 10 feet in outside diameter and the

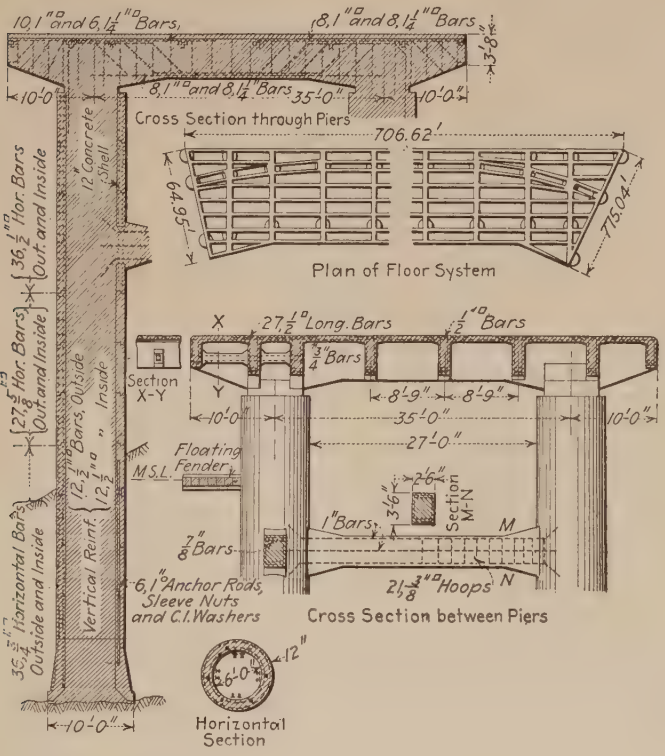

Fig. 90. Wharf Platform on Concrete Columns, Balboa, C. Z.

upper portion 8 feet, with walls one foot thick. The concrete in the shells was mixed in the proportion of 1: 2: 4. The vertical reinforcing rods were placed in holes moulded in the shells and rods were connected, at each joint of the latter, by sleeve nuts. The interior of the columns was filled with 1: 3: 5 concrete, reinforced with old rails, after sealing and removing the water. The greater part of the mud and clay was removed by hand excavation, as water

jets did not work well in the clay, even with 120 pounds' pressure and orange-peel buckets were not as efficient as hand work. The work being performed in the dry permitted the placing of heavy transverse and longitudinal reinforced-concrete braces between the columns below low-water level. The mean range of tide is about 13 feet at this location and the bottom along the outside of the wharf was dredged to 40 feet below mean sea level after the wharf was built.

Block-and-bridge Piers

Two masonry piers have been built on the block-and-bridge plan in New York. Pier New No. 1 was begun in 1872 and completed in 1876, and as it was the first pier to be seen from vessels coming from the sea, its design was of a monumental character. It is 453 feet long and 80 feet wide and is formed of 18 semicircular concrete arches of 11 feet, 6 inches radius, 18 inches thick at the crown, supported by cross-walls 5 feet, 6 inches thick, except at the outer end of the pier, where the wall is 12 feet, 6 inches thick. These cross-walls are built of concrete blocks made in air and set by derricks and divers. They rest on beds of concrete deposited by means of buckets in weighted, wooden forms placed on the rock bottom, which is from 25 to 50 feet below the water surface. The sides of the pier are faced, above low tide, with granite about two feet thick. This structure is said to have cost $14.00 a square foot.

Pier A was built in 1885, not for commercial purposes, but for the offices of the Department of Docks. The deck is of concrete arches, one foot thick at the crown, supported on longitudinal steel girders resting on cross-walls of concrete blocks, similar to those in Pier 1. The cross-walls are 5 feet, 6 inches thick at the bottom and 4 feet, 9 inches at the top and are spaced 35 feet apart. The cost was about $11.60 a square foot.

A small block-and-bridge pier was built near Glen Cove,

N. Y., for a yacht landing. In this case the blocks were hollow, reinforced concrete caissons set in place by large floating derricks and filled with sand. The bridges were of wood.

Solid-filled Piers

Solid-filled piers may be divided into two classes. First, those in which there is a pile platform outside of the retaining structure, and second, those in which there is no such platform, vessels being moored directly against the vertical or nearly vertical face of the retaining wall. The former type is usually the cheaper in first cost and most of the large solid-filled freight piers, except the narrow ore piers of the Great Lakes, are of this type. This is due to the fact that such piers are usually built in comparatively shallow water, permitting the use of a wall of relatively small section with the bottom sloping from the wall to the edge of the platform.

An example of filled-in piers built with the idea of reducing the first cost to a minimum is that of the Bush Terminal. These piers are located on a sand-and-gravel bottom with a general elevation slightly below low water. The main retaining structure is a line of wooden sheet piling supported by tie rods across the piers and a bank of riprap in front, as shown in Fig. 43. The filling was obtained by dredging the slips. The wharf platform is of the usual New York type of timber construction. These piers were covered with sheds and the flooring over the filled portion was of plank laid on wooden sills resting on the filling. They have lasted from 12 to 15 years without many repairs except where they were damaged by fire. The wooden flooring has been replaced by concrete in some places and some of the piers have recently undergone extensive repairs to the outer portion of the platform.

A design for similar piers adjoining those of the Bush Terminal but of more durable construction was made by the New York Dock Department, as shown in Fig. 91, but was abandoned in favor of the design shown in Fig. 70.

A solid-filled pier without a marginal platform, known as Commonwealth Pier No. 6, and used for the fishing industry, was completed in 1914 by the Board of Directors of the Port of Boston. The pier is 1200 feet long and 300 feet wide. The fill is retained by a granite masonry wall which is illustrated in Fig. 19.

Two notable piers are being built at Victoria, B. C., with vertical walls, extending 35 feet below low water, formed of concrete caissons on a rubble mound in water

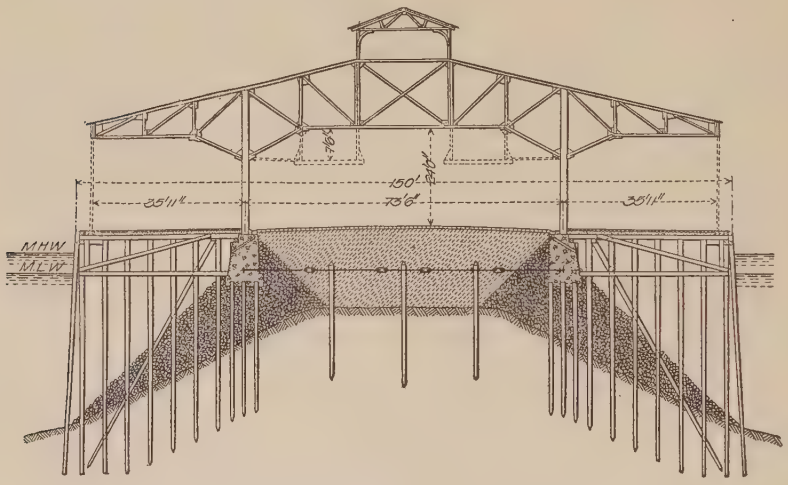

Fig. 91. Design for a Solid-filled Pier, Brooklyn, N. Y.

up to 60 feet deep. The wall is shown in Fig. 30. These piers are 800 feet long and 250 feet wide, with a 300-foot slip between them.

Another large pier of this type is being built at Halifax by the Canadian Government. It is the first of a group of six similar piers which are planned for a railroad and steamship terminal. The wall in this case is composed of stacks of cellular, pre-cast, concrete blocks filled with concrete and stone which are described on page 63. The choice of this design was influenced by the large amount of rock to be disposed of from the excavation of the slips to

the required depth of 45 feet, and of materials from the large cuts required for the construction of the railroad leading to the terminal. Other considerations were the

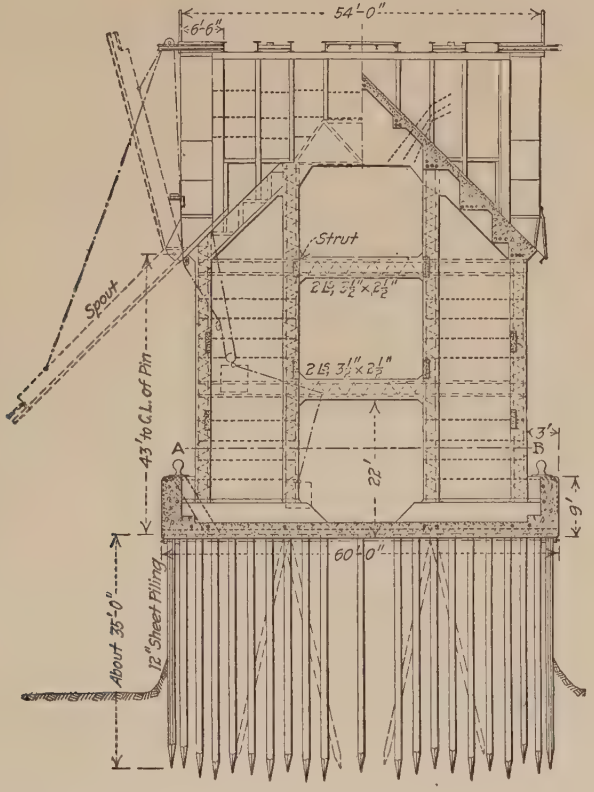

Fig. 92. Solid-filled Ore Pier with Wooden Sheet Piling, Marquette, Mich.

ground swell and waves which rendered the use of floating plant difficult and uncertain.

Several of the solid-filled coal and ore docks on the Great Lakes have been described in Chapter IV. A number of these piers have been built recently, in which sheet piling of wood or steel is used to retain the filling instead of the timber cribs formerly used.

Fig. 92 illustrates one at Marquette, Mich., in which

wooden sheet piling is used, and inclined piles are added to increase the stability. The ore bins and their supports are of reinforced concrete. A feature is the sheathing of the face of the concrete with steel plates from 6 inches below the water level to 3 feet above it to prevent disintegration by frost and abrasion. Fig. 93 shows one of

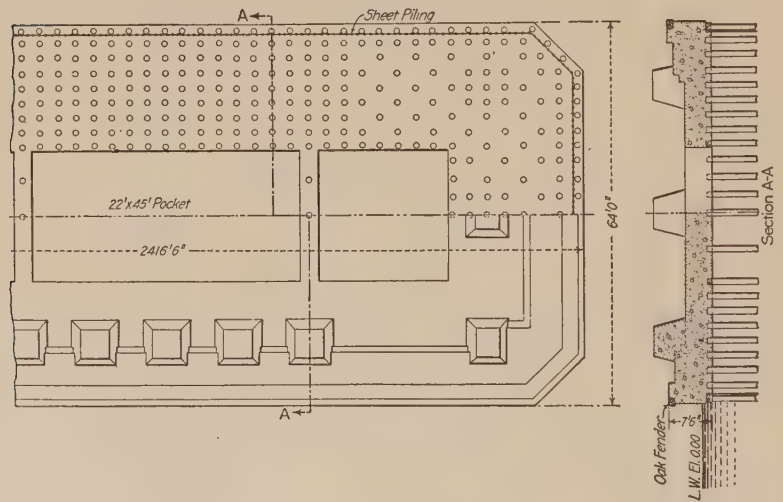

Fig. 93. Solid-filled Ore Pier with Steel Sheet-piling, Duluth, Minn.

more recent date at Duluth, Minn., in which steel sheet-piling retains the filling.

In these narrow piers the columns supporting the heavy bins are supported on concrete footings, carried on wooden piles cut off just above the water line. These footings also form the exposed facings of the piers. The sheet-piling retains the filling, the only function of which is to stiffen the piles and to give a surface on which to deposit the concrete. The sheet-piling is supported at the tops by rods embedded in the concrete and extending from side to side of the pier.

CHAPTER VI

WHARF AND PIER SHEDS

Sheds in General

The function of sheds on wharves and piers is to shelter freight and passengers from the elements and to prevent theft

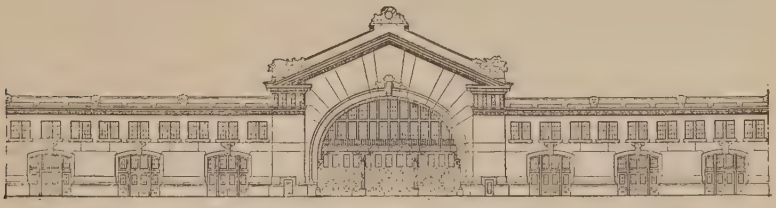

Fig. 94. Inshore Elevation, Reinforced Concrete Construction, Chelsea Pier Sheds, New York, N. Y.

of merchandise. They are usually used for sorting both inbound and outbound freight and for its temporary storage while in transit between the vessel and the warehouse, but in some cases are used as warehouses.

The general features of their construction are not essentially different from those of similar structures not located on the water front and are usually regulated by the building laws of the cities in which they are built.

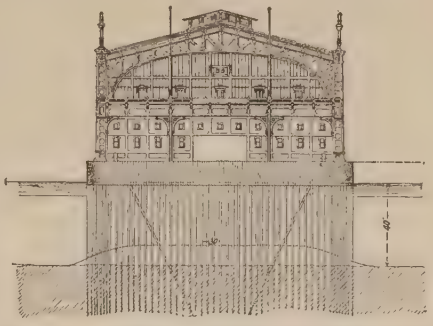

Fig. 95. Outshore Elevation, Sheet-metal Construction, Chelsea Pier Sheds, New York, N. Y.

On deep-pile foundations lightness is of great importance in decreasing the cost, and on piers subject to

unequal settlement and to distortion from the impact of vessels elasticity is essential.

Pier sheds are one or two stories in height. The upper

Fig. 96. Inshore End-33rd St. Pier Shed, Brooklyn, N. Y., Showing Sheet-metal Construction.

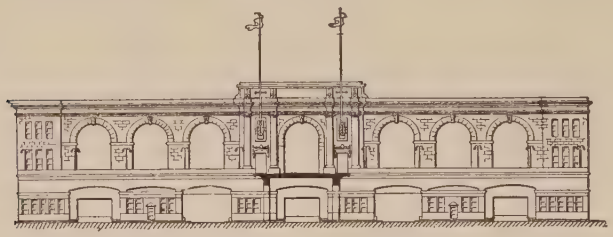

Fig. 97. Front Elevation of Head-house of Hollow-tile and Stucco, Commonwealth Pier 5, Boston, Mass.

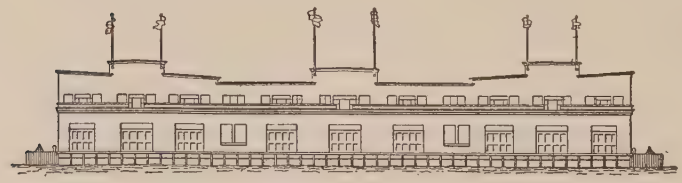

Fig. 98. Outshore End of Shed, Commonwealth Pier 5, Boston, Mass.

story is commonly added for the use of passengers, but there are a few very large piers equipped with two-story sheds on which freight is handled on both floors.

The inshore ends of pier sheds are often joined to bulkhead sheds, extending along the bulkheads on each side of the pier, and to head-houses on the bulkhead which contain offices and are in many cases two or more stories in height. The façades of such buildings as well as the outshore ends of the pier sheds call for architectural ornamentation and embellishment to fit the æsthetic requirements of the structure and the locality. Sheet copper or galvanized iron on steel frames which are more or less elastic are frequently used where the foundations are liable to settlement, but on the Chelsea Piers in New York the face wall shown in Fig. 94 is of concrete reinforced with expanded metal supported on steel girts. As this wall is on filled-in land overlying deep mud, settlement is expected and the wall at the ends of the piers and the steel frame of the bulkhead sheds are arranged so that they can be jacked up independently of each other whenever the necessity may arise. The details of this arrangement are shown in Figs. 100 and 101. Where the foundation is not liable to settlement, brick, concrete, cement mortar on

Fig. 99. Head-house, Hawaiian American Line Pier, San Francisco, Cal.

metal lath, and hollow tile covered with cement stucco have been used.

The equipment of pier sheds with cargo-handling devices is described in Chapter VIII. In this connection may be mentioned a shed of the Tehuantepec Railway which has the novel feature of having removable hatches in the roof, through which the freight is hoisted and lowered by locomotive cranes.

A number of piers in New York and other cities have two-story sheds the upper deck of which is designed for recreation purposes and the lower deck for freight, as illustrated in Fig. 102.

Fire-resisting Construction

Fire-resisting construction, though it increases the cost and weight, should receive most careful consideration in the design of sheds which are to contain large quantities of valuable freight. Many existing sheds on both the Atlantic and Pacific coasts are built entirely of wood, but in recent years there has been a tendency to use only incombustible or fire-resisting materials. Unprotected steel frames are sometimes cheaper than those of wood, but do not last as long in case the freight takes fire. Sometimes a combination of the two is economical, as at Seattle, where a two-story shed has timber posts, Bethlehem I-beam girders, and deep timber joists. Some steel frames have been encased in tile to render them fire-resistant, but the increase in weight is considerable and increases the cost of pile foundations. The steel columns, second-floor trusses, and joists of the B. A. R. R. piers in Boston are protected with plaster board which is comparatively light and a galvanized sheet-iron jacket has been used in some New York Piers. The unprotected steel frame, when used with an adequate equipment of automatic sprinklers, offers some solution of the problem, but to build a really fire-proof shed the frame of which is light, elastic, cheap and economical presents many

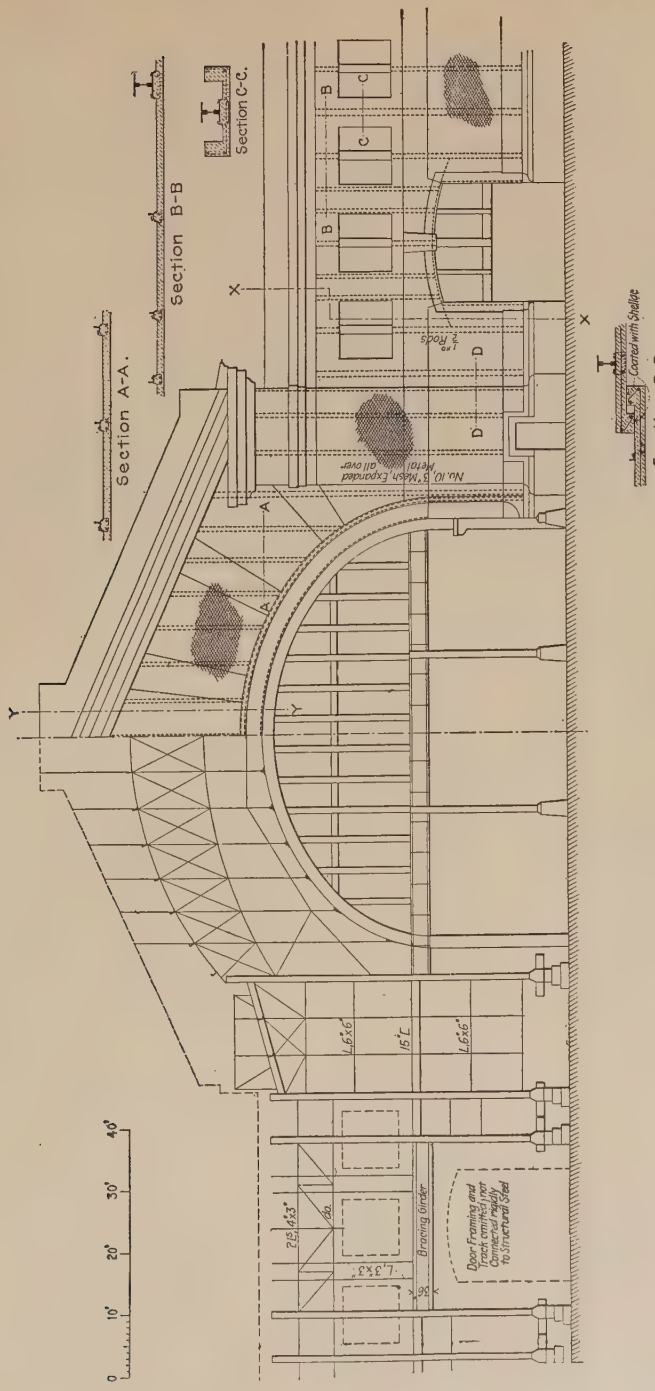

Fig. 100. Details of Concrete Wall, Chelsea Pier Sheds, New York.

difficulties. Reinforced concrete is heavy and expensive and requires many columns at frequent intervals which obstruct the handling of freight. Plate girder construction has the same objections and is uneconomical in the use of the metal.

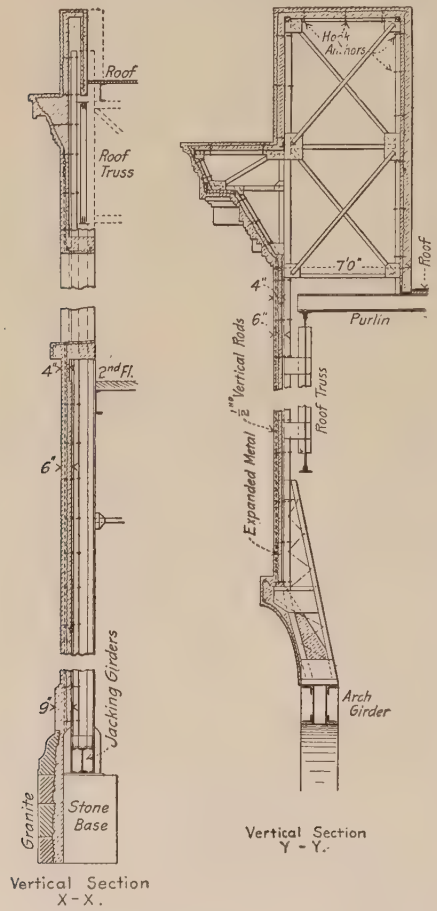

Fig. 101. Details of Concrete Wall, Chelsea Pier Sheds, New York.

This problem apparently has been solved in large steel pier sheds recently completed in the Panama Canal Zone, by covering the individual members of the roof trusses, longitudinal trusses and monitors with cement mortar $1\frac{1}{2}$ inches thick. All the members of the trusses were covered except the upper chords which were enclosed by the concrete roof slabs. Light wooden platforms on wheels were provided for the workmen to stand on in performing the work. The steel was first thoroughly cleaned with wire brushes and then covered with expanded metal, fastened with wire. Wooden troughs were supported under the horizontal and inclined members and filled with mortar, the mortar over the vertical legs of the angles being shaped with a combined trowelling and screeding tool. No forms were used on the vertical members which, together with the joints were plastered and trowelled.

The cement gun was tried but was unsuccessful because the waste due to the small size of the truss members was excessive. Wooden forms for the entire section were also

Fig. 102. Recreation Pier, New York, N. Y. Lower Deck used for Commerce.

tried, but on account of the thinness of the mortar coat, could not be entirely filled.

The cost of the fire proofing of the trusses was about 12 cents per square foot of floor area (see appendix), and even if the labor should cost much more than it did at Panama, a shed frame of steel protected in this manner would, in many cases, be cheaper than reinforced concrete or any other really fire-proof construction.

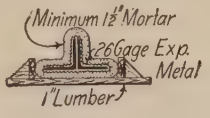

Fig. 103. Fire-proofing for Steel Shed Frames, Balboa, C. Z.

Framing

Shed posts, except those located in the walls, form a serious obstruction to the movements of wagons and trucks and should be as limited in number as possible on piers on which such vehicles enter. In the North German Lloyd piers at Hoboken, N. J., this was considered to be of suffi-

cient importance to warrant the extra cost of suspending the second floor from the roof trusses as shown in Fig. 104. About 20 feet is an ordinary spacing for trusses. This fits ten-foot spacing of pile bents and gives an economical length for purlins. Sheds up to 100 feet in width are frequently built in one span. For those of 125 feet two spans are economical and for 150 feet three spans give a good arrangement of posts.

The usual clearance under roof trusses and under floor beams in two-story sheds varies from 17 to 22 feet. If

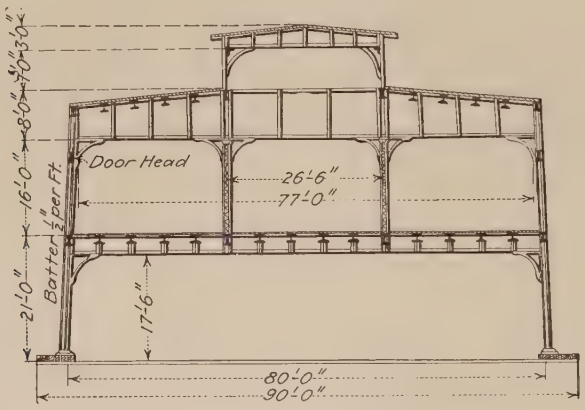

Fig. 104. North German Lloyd Pier Shed, Hoboken, N. J.

travelling cranes and telpherage machines are used for handling freight, this height is increased by from 10 to 15 feet.

A quadrilateral form of truss is the most economical for roofs. The longitudinal members of the frames, the bracing of the end walls, and the diagonal bracing in the roof are similar to those of other structures and need no particular description.

Side Coverings

The materials most used for the side covering of sheds on pile piers are wood, galvanized sheet iron, and reinforced concrete. On solid-filled wharves which afford good founda-

tions hollow tile and reinforced concrete are more commonly used.

Corrugated galvanized iron is cheap, light, elastic, and incombustible. When exposed to the air, however, it deteriorates rather rapidly when near salt water, and the greatest care should be taken to keep it covered with an impervious and unbroken coating of paint. Before the paint is first applied the galvanized iron should be carefully washed with an alkali in order to insure adhesion. Even with the greatest care it is difficult to make paint stay on it for any length of time, owing to the formation of zinc chloride on the surface wherever the salt air reaches the metal.

Corrugated iron protected on both sides with a layer of asbestos felt treated with asphalt and an outer layer of asbestos fabric has recently been placed on the market. It is claimed for this material that it has all the advantages of galvanized corrugated iron and that it is very durable without painting and requires little or no maintenance.

The use of wood for siding is objectionable on account of the exterior fire risk. If covered with sheet metal on the outside this risk is diminished, but it still aids the spread of interior fires.

Roofing

The "tar and gravel" type of roof laid on wooden plank has many advantages over other materials in the ease and cheapness with which it can be constructed, its elasticity and lightness, and its resistance to fire on the outside. It has one disadvantage in that unless it is protected on the underside it will aid in spreading a fire. If it is protected by plastering it may be subject to dry rot. This may be prevented by the process known as vulcanizing or similar methods of preservation. Such protection, however, adds to the expense, and the fire risk may be safeguarded to a certain extent by automatic sprinklers. On the B. & A. R. R. piers in Boston the heavy 3-inch roof plank are pro-

tected on the under side with plaster board. Fire-retarding paints are also of some assistance.

Concrete tile is fairly light and has a pleasing appearance, but requires a steep slope, which is objectionable in wide, sheds on account of the resulting height and wind stresses.

Reinforced concrete is heavy and inelastic and is liable to be cracked by the impact of vessels on an elastic pier, but it excels in fire-resisting qualities inside and out.

Sheds should be provided with a cornice along the sides to form a gutter and prevent the rain water from running off the edges. Down spouts should be carried inside the building. The lower portion should be of steel pipe to prevent damage from wagons and trucks. Cornices should not, however, overhang in such a way as to interfere with cargo-hoisting gear. Sheds are sometimes built with sloping sides, which is of some advantage in this respect, but such sloping sides reduce the storage capacity, do not permit the use of sliding doors, and are unnecessary except for piers for the accommodation of square-rigged vessels.

Lighting and Ventilating

Sheds should be well lighted and ventilated. The cheapest method of attaining the result is by the use of skylights and galvanized iron ventilators. Monitor skylights with machinery for opening and closing movable sashes are better but much more expensive. Where it is not necessary to provide doors extending in height to the eaves of the shed a row of windows just under the eaves is of advantage. As wired glass in metal frames is one of the best fire-resisting materials the window area should be as large as possible.

Doors

The design of cheap and efficient doors for the sides of pier sheds is a subject of considerable difficulty. For steamship piers it is necessary to have the doors come opposite all the hatches in the vessels, and for this reason

nearly all recent pier sheds have doors in every panel. Doors for freight which is hoisted in and out of steamships and other vessels should be as high as possible to allow the merchandise to be swung inside the shed. Those for freight handled by trucks do not require great height. Doors for pier sheds should be capable of being rapidly closed by one man in case of fire, showers, or heavy winds. There are four types in general use: horizontally sliding, vertically swinging, vertically lifting and folding, and rolling.

Horizontal sliding doors are the simplest and cheapest. They are usually made as light as possible, with wooden frames covered with diagonal sheathing boards protected on the outside with sheet metal, as shown in Fig. 105. They are hung on tracks with ball or roller bearing hangers, and where the doors fill every panel in the side of the shed provision must be made for one door to pass another. This type of door is liable to jam when being closed in a heavy wind unless it runs in a groove at the bottom provided with rollers to prevent friction; and such grooves are liable to interfere with freight-handling trucks. On account of the necessary lightness of construction this type is not very durable in the large sizes. For openings 20 feet square on steamship piers such doors are usually made in two leaves and this is about the limiting size for this type.

Vertically swinging doors may be of similar construction or may be made much heavier with steel frames and covering. When not counterbalanced they should not reach in one piece below the height of a man from the deck, as they are liable to fall and cause accidents. The lower portion of the opening should be closed by small multiple shutters or by a flap folded back on the upper portion of the door. Swinging doors which reach the deck have also the disadvantage that they cannot be opened when freight is piled against them. Large vertically swinging doors if strong enough to be durable are so heavy that one man cannot

raise them without the aid of counterweights and gearing, which add very greatly to their cost.

An elaborate door of large size used on the Chelsea piers

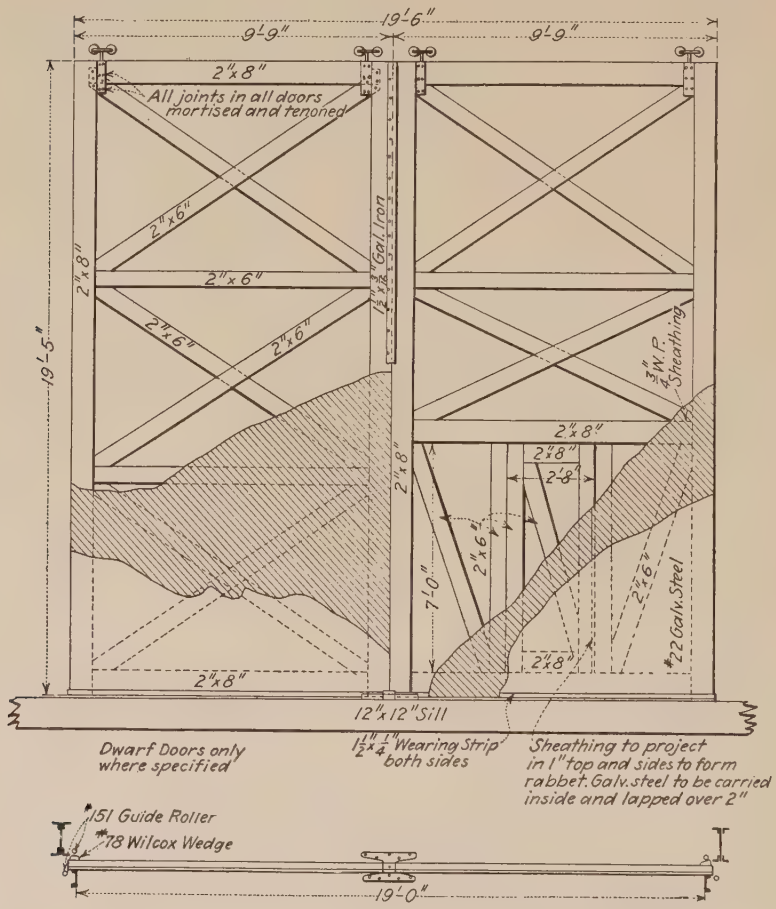

Fig. 105. Wooden Door for Pier Sheds.

in New York City is shown in Fig. 106. The upper portion is swung up by means of a fourfold rope tackle. The lower portion is raised vertically in guides at the sides by means of counterweights and gearing operated by a hand chain. It is not connected to the upper portion, but

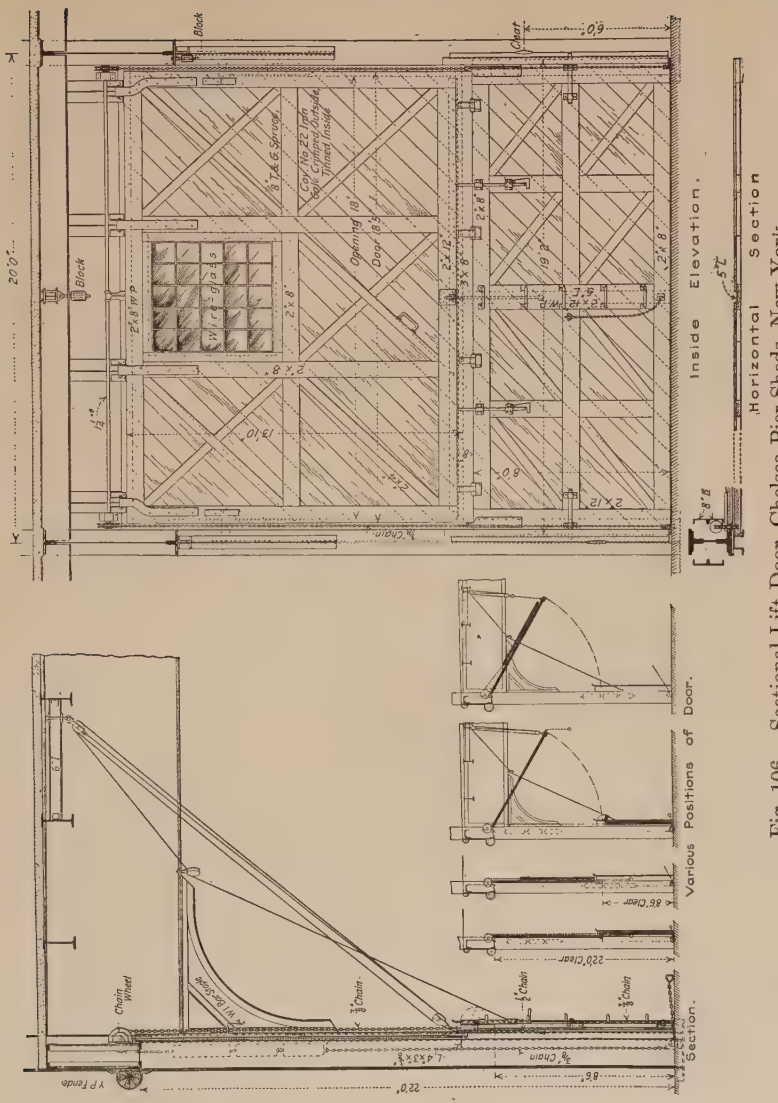

Fig. 106. Sectional Lift Door, Chelsea Pier Sheds, New York.

the joint between the two parts is closed by a hinged flap. When in the upper position the lower portion overlaps the upper and may be swung up with it. This arrangement allows (1) the entire doorway to be open or closed; (2) the upper portion to be closed and the lower open for the passage

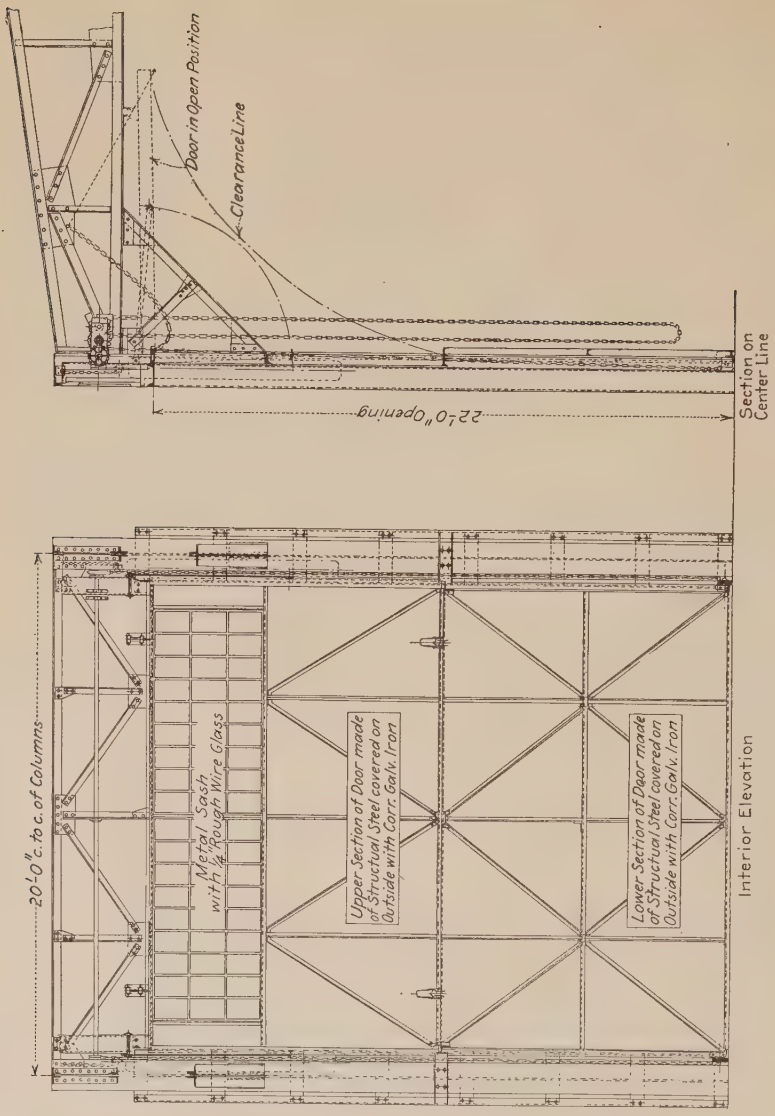

Fig. 107. Two-piece Folding Steel Door.

of men with hand trucks; and (3) the upper portion open for light and air and the lower portion closed to prevent theft of merchandise. These doors are used in every panel on the sides of the piers and those in adjacent panels

do not interfere with each other. One man can close them but cannot raise the upper portion alone.

Doors to lift vertically are made to fold when raised, as in Figs. 107, as there is not sufficient headroom in pier sheds to make them in one piece. Such doors may be opened when freight is piled close against them.

Steel rolling doors for large openings formerly had many objections. They were liable to rust and stick and failed when attacked by fire. They have been greatly improved in recent years and have been placed on many piers of recent construction where the openings are not too large.

All patterns which require gearing or other machinery for operation are comparatively expensive and form a large item in the cost of a shed.

Wicket or dwarf doors for the passage of watchmen and the escape of men in case of fire should be provided at convenient intervals.

Doors at the ends of the sheds are usually of the sliding type divided into units which can be handled by one man or may be of larger size and operated by machinery.

Protection against Damage and Accident

The exterior corners of sheds should be protected against damage by mooring lines. The outside of lintels and doorposts should be similarly protected against injury by hoisting lines, and the protection should be of such materials that it will cause a minimum of wear on the ropes.

Exterior walls and all posts and doorways require protection against damage from wagons and hand trucks. Wooden sheathing is commonly used for the inside of corrugated iron siding, but it increases the amount of combustible material. Wheel guards of various forms are used to prevent wagons from striking doorposts and interior shed posts.

The distance between the side of the pier shed and the edge of the pier should be sufficient to provide a safe space

for handling the mooring lines of vessels. It usually varies from one to six feet. There should be some sort of foot rail on the edge of the pier to prevent men from slipping off. In New York it is customary to make this rail or "backing log" one foot high, but this interferes in many cases with gangplanks and freight handling. A hand rail should be placed on the outside of the shed for further protection against men falling overboard.

Examples of Typical Sheds

A simple form of truss entirely of wood for a pier 70 feet wide is shown in Fig. 108. This truss is built of planks.

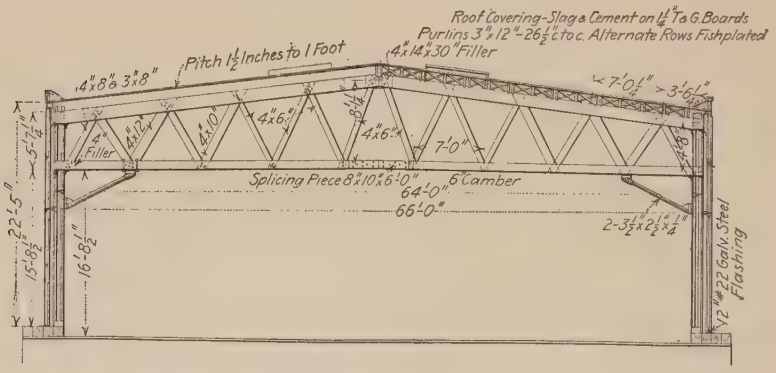

Fig. 108. Wooden Shed Truss, for 70 Foot Wide Pier, N. Y. Dock Co.

It has the advantage that the lumber can be obtained in the sizes used of superior quality at a reasonable price. The large amount of wood surface and the spaces between members of the chords of the trusses are objectionable on account of the fire risk. The sides of the shed were made entirely of steel, to comply with a local building law. The trusses are spaced 20 feet apart. A steel truss on similar lines is shown in Fig. 109.

A two story pier shed with timber frame recently completed at Seattle, is illustrated in Fig. 110. It was designed for a second floor live load of 300 pounds per square foot and 30 pounds dead load. A maximum fibre stress of

1,600 pounds was allowed for the timber with 400 pounds per square inch in compression across the grain. A feature is the cast iron caps on the columns which are en-

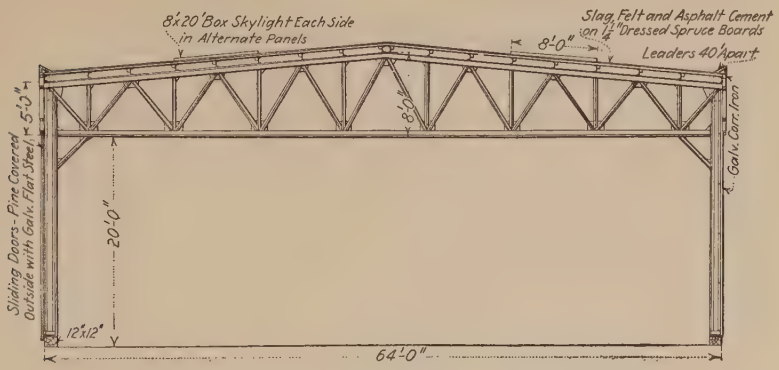

Fig. 109. Steel Shed Truss for 70 Foot Wide Pier.

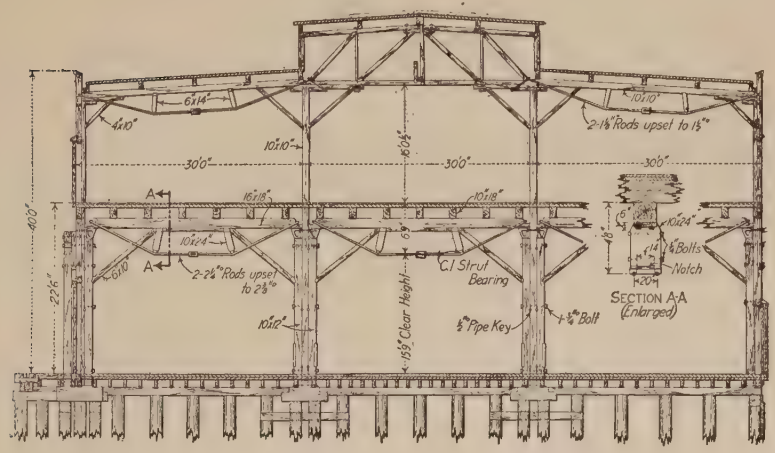

Fig. 110. Two-story Timber Shed, Seattle, Washington.

larged at the top to increase the bearing area of the beams. This design was chosen in competition with one of steel which required 30-inch I beams in place of the 16 inch by 18 inch trussed, Douglas fir timbers. It was estimated that the wooden frame would save 20% over the steel, and that it would last for 20 years.

Such a frame as this would probably withstand a fire in the contents of the building fully as long as one of unprotected steel though the size of the timbers in the roof are rather small for slow burning construction.

Fig. 111 shows a very economical shed for a 150-foot wide pier. The trusses are 20 feet apart. Two light wooden sliding doors 20 feet high are used in each alternate panel.

A similar truss, but of quadrangular form with cargo masts, is shown in Fig. 112.

A shed with steel frame and reinforced concrete sides and

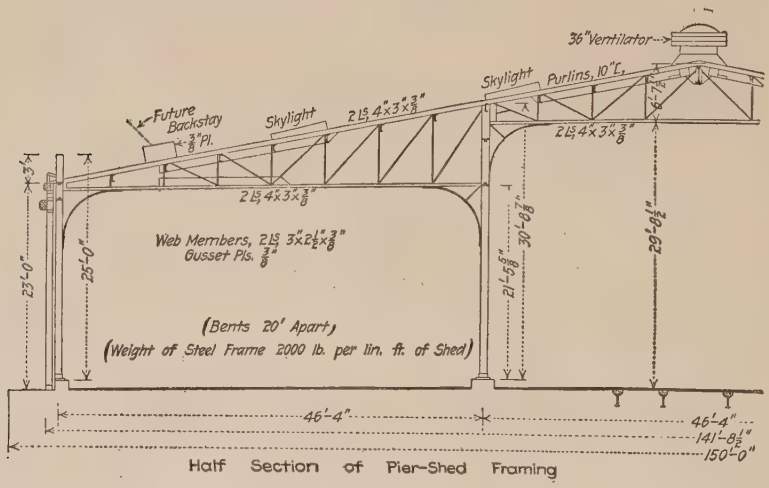

Fig. 111. Pier Shed 33d St., Brooklyn, N. Y.

roof built on a pile pier on deep mud bottom is illustrated in Fig. 113.

A similar shed one story high on an adjacent pier was arranged so that the walls were independent of the floor and could be jacked up in case of settlement. The walls, however, gave considerable trouble from cracking. The interior columns and the floor and roof beams of these sheds were not protected against fire in any way.

Fig. 114 shows the sheds on the reinforced concrete pile piers at Havana. The columns and roof beams are reinforced with rivetted structural steel strong enough to

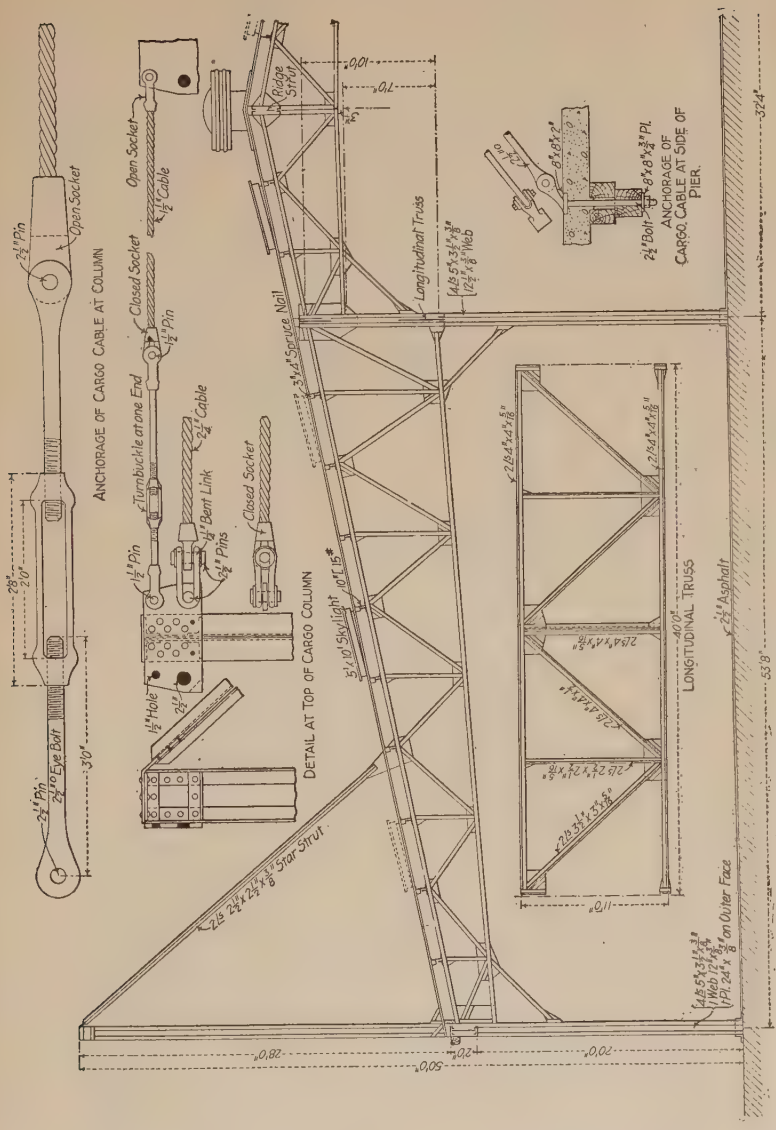

Fig. 112. Pier Shed 35th St., with Cargo Hoists, Brooklyn, N. Y.

support the forms in order to facilitate erection. The sides and roof are of cement mortar on metal lath with raised ribs. The down spouts for rain water were placed in the centre of the shed columns.

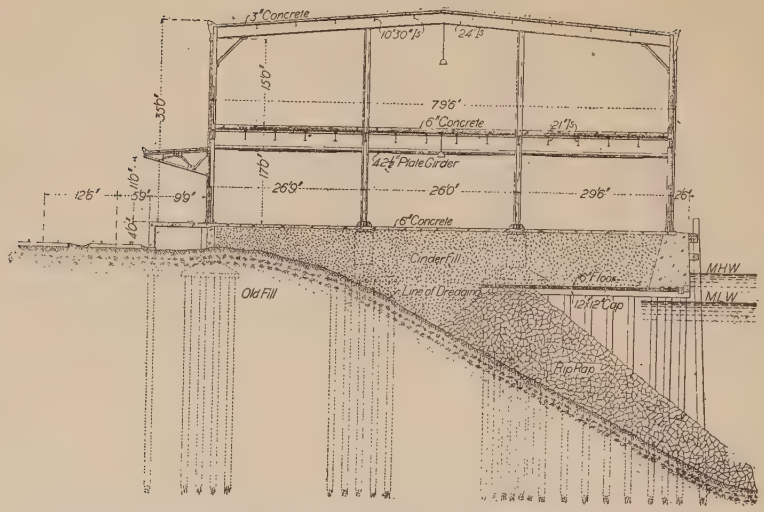

Fig. 113. Pier Shed with Steel Frame and Concrete Roof and Sides, D. L. & W. R.R., Pier 9, Hoboken, N. J.

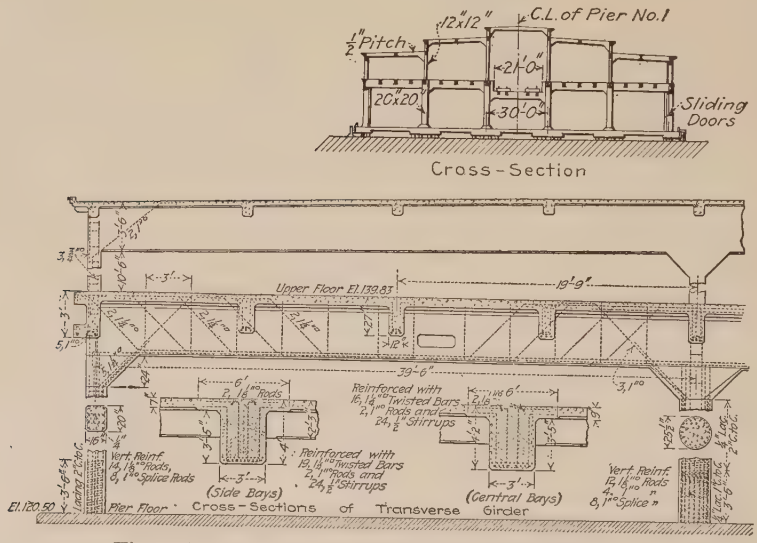

Fig. 114. Reinforced Concrete Pier Shed, Havana, Cuba.

An unusual form of shed is shown in Fig. 115. In this case the posts were placed 10 feet from the sides of the

building and sliding doors arranged to pass each other were hung from the eave-truss. Grooves formed of angle iron were placed in the deck to hold the lower edges of the doors.

Fig. 116 shows a timber truss of 100 feet span on the municipal docks of Los Angeles, Cal., also a steel truss of the same size with cargo masts.

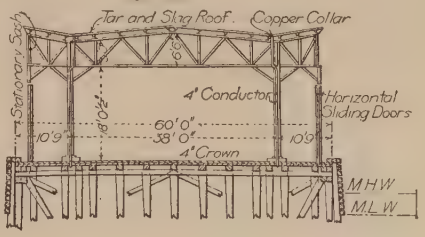

Fig. 115. Sheds on Piers 40 & 41 E. R., New York.

A steel shed with concrete roof and siding is shown in Fig. 117. The trusses were spaced 30 feet apart.

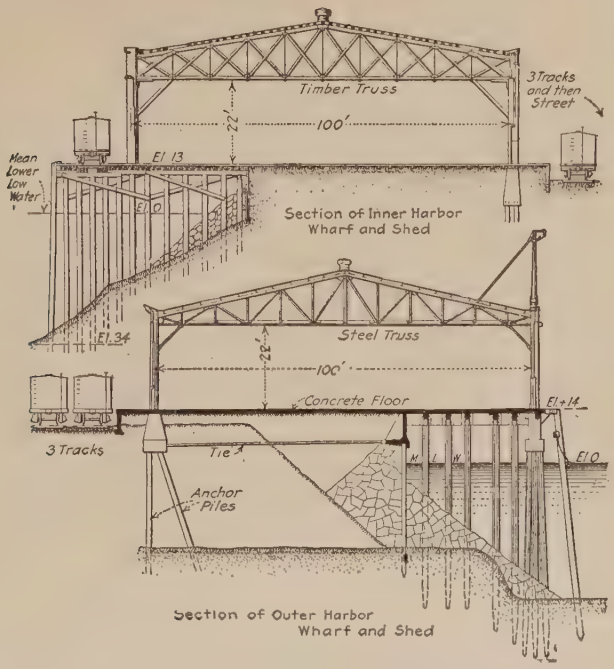

Fig. 116. Timber & Steel Shed Trusses, Los Angeles, Cal.

The two-story steel sheds on the Chelsea piers in New York are illustrated in Fig. 118. The cargo masts are of

elaborate construction and carry a foot walk for men to rig the hoisting gear. The side covering was of galvanized corrugated iron and the roofs were of felt and slag on plank.

The shed on the large concrete pile pier at Halifax is

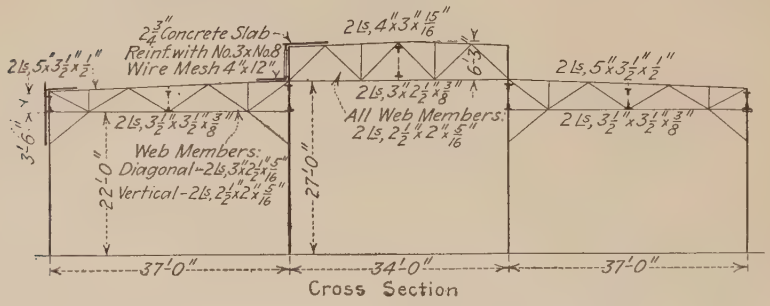

Fig. 117. Shed with Steel Frame and Concrete Sides and Roof, Pier No. 38, San Francisco, Cal.

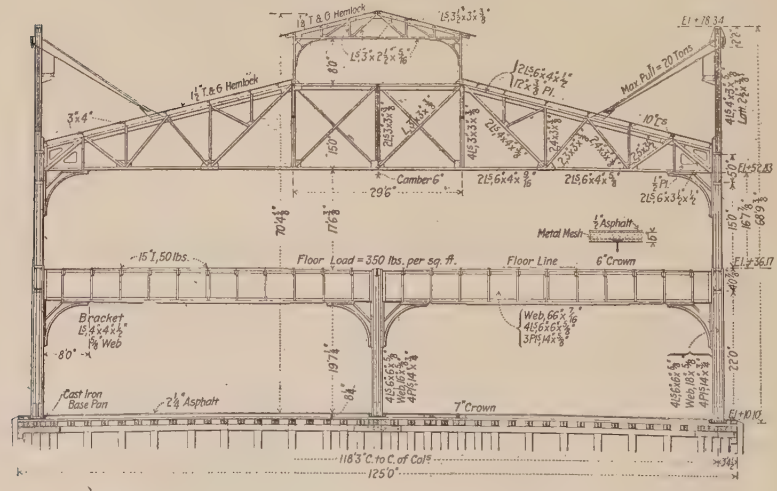

Fig. 118. Two-story Shed, Chelsea Piers, New York, N. Y.

illustrated in Fig. 84. This shed is 200 feet wide and divided into five bays. It is designed for a live load of 500 pounds per square foot on the second floor and 110 pounds on the roof. The roof is of concrete, on which is laid a layer of boards and a felt and gravel surface finish. The bents

are spaced 18 feet apart. The doors of the sliding pattern are in alternate panels in the upper story, but are continuous in the lower. The lower columns are 25 inches in diameter and are protected at the bottom with $\frac{1}{4}$-inch steel plates.

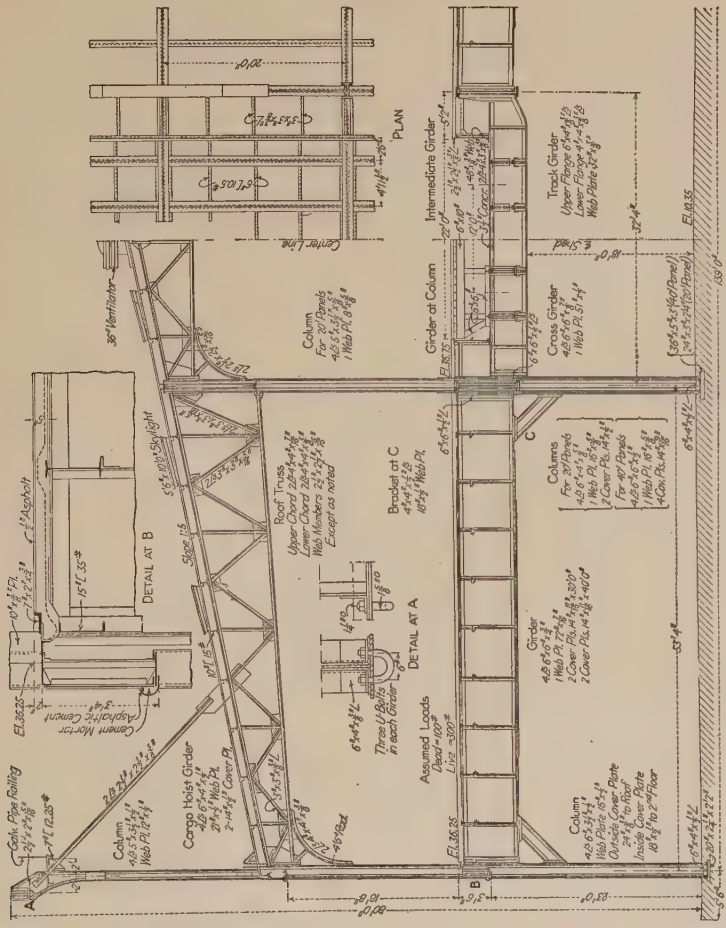

Fig. 118a. Two-story Steel Shed, 46th St., New York.

Expansion joints were provided in the roof of the shed, but not in either the upper or lower decks.

A two-story steel shed for the 1000-foot 46th Street pier in New York, shown in Fig. 118a, although it may be of limited interest in that it is designed for the latest and larg-

est transatlantic passenger steamers, contains many interesting details. The posts are spaced 20 feet apart longitudinally except for a distance of 400 feet at the inner end, where those in the rows on each side of the center line are spaced 40 feet apart in order to reduce the obstruction to wagons and trucks. The depth of the soft mud in the outer portion of the pier rendered the 40-feet spacing impracticable except at the inshore end. The interior posts are 32 feet 4 inches apart transversely, which was considered sufficient for a driveway, leaving unobstructed bays about 50 feet wide on each side. The second floor consists of a reinforced concrete slab supported on steel beams. Provision is made for depressed railroad tracks on this floor, the depression being filled with a temporary wooden platform, as there is no railroad connection with the pier at present. The cargo hoist girders on this pier are of structural steel supported on posts spaced 20 feet apart and are designed for two five-ton loads applied five feet from the supports with 100 per cent added for impact. Light and ventilation are afforded by ventilators and skylights instead of by the monitors used on the Chelsea piers.

CHAPTER VII

EQUIPMENT OF WHARVES AND PIERS

Fenders

Fenders have two functions: one is to prevent injury by abrasion and the other is to absorb the energy of impact of vessels coming in contact with the wharf. The necessity

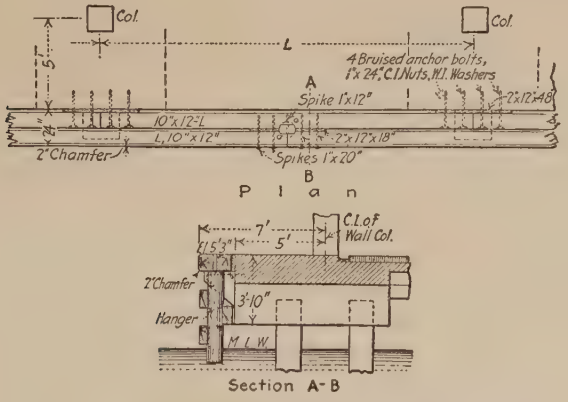

Fig. 119. Fender on Concrete Piers, Havana, Cuba.

of fenders depends somewhat on the absence or presence of waves, swells, and currents in the water adjacent to the structures. They are almost universally used in this country, but are often omitted from European structures, particularly in the wet docks. Wooden pile structures, on account of their elasticity, need only protection against abrasion, but on inelastic wharves and piers of steel, stone, or concrete, compressible fenders to prevent damage to both vessel and wharf are usually considered necessary. There are some examples, however, of inelastic piers on which the fenders are compressible only to the extent furnished by

timber fixed to or suspended from the face of the structure. Examples are those shown in Figs. 19, 50, 80 and 119.

Fenders are of three general types, — fixed, spring, and floating. Fixed fenders may take the form of piles, vertical or horizontal strips, or sheathing. Horizontal strips of heavy timber should be interrupted at frequent intervals with vertical chocks. If this is not done they may be ripped off by tugs and similar vessels which have considerable sheer and projecting guards and waling strips.

An excellent form of fender for the sides of wooden pile

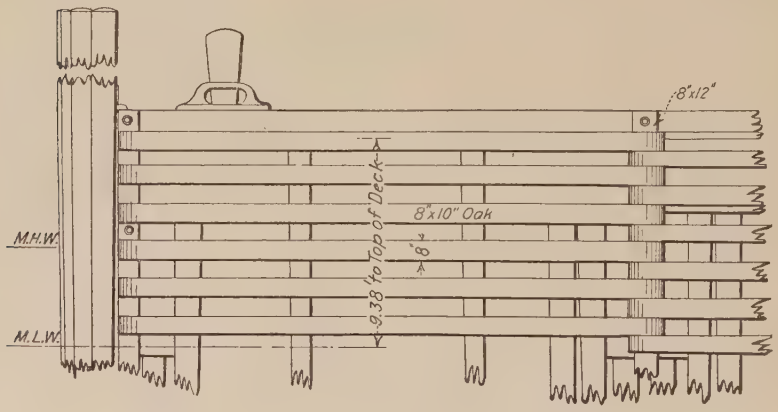

Fig. 120. Continuous fendering for Wooden Piers.

piers is shown in Fig. 2. The piles may extend above the deck of the piers if required.

Another form covering the entire exposed portion of the sides of wooden piers for use in places where there are many car floats, scows, and other square-cornered vessels which would damage the fender piles ordinarily used, is shown in Fig. 120. Such fendering should always be put on with a space between the strips in order that persons who fall overboard may climb out on them.

The standard corner fender for the wooden piers of the New York Dock Department and the rounded corner used for piers for large passenger steamships are shown in Fig. 2.

Fenders for concrete surfaces are shown in Figs. 31, 76, and 121.

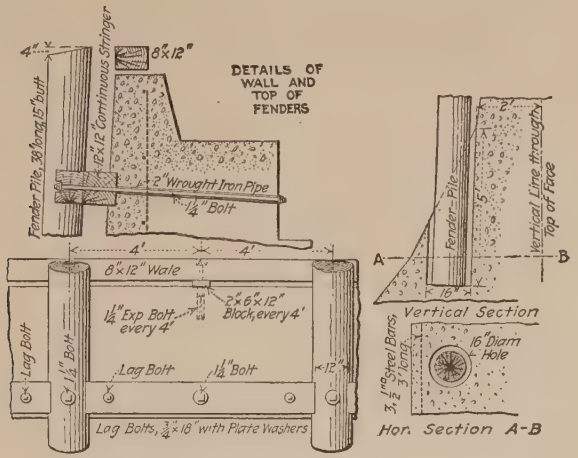

Fig. 121. Fender for Concrete Wall, Oakland, Cal.

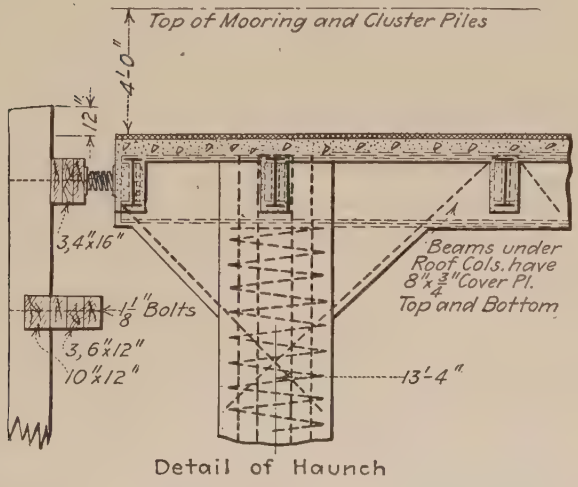

Fig. 122. Spring Fender for Concrete Pier, San Francisco, Cal.

A spring fender supported on fender piles for a concrete pier at San Francisco is shown in Fig. 122.

It was found, however, that the creosoted exterior por-

tion of the fender piles was rapidly worn off by vessels and the piles destroyed by the teredo. This required such frequent renewals of the piles that the suspended spring fender shown in Fig. 123 was substituted on piers of recent construction.

Floating fenders consisting of round logs or rafts built up of timber are more suitable for masonry walls than for pile structures, as they cause rapid wear of the piles. This is particularly undesirable where the piles are creosoted, as the marine borers attack them as soon as the creosoted

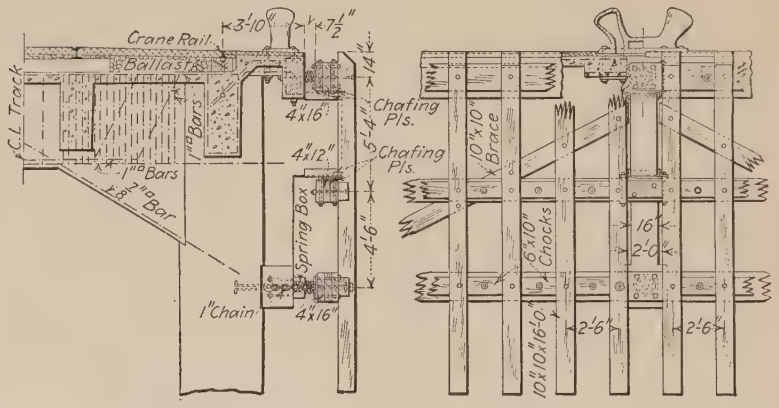

Fig. 123. Suspended Spring Fender for Concrete Pier, San Francisco, Cal.

exterior portion is worn through. Examples are shown in Figs. 35, 57, 68 and 90.

Compressible fenders made of bundles of saplings bound with wire are used on the large concrete-pile pier at Halifax.

A fender consisting of a row of spring piles, connected by horizontal wales, located about a foot from the face of a concrete wharf wall but not connected to it, has been used in some places.

On the composite pile pier at Port au Prince, Haiti, which is more or less elastic, creosoted fender piles sheathed above water with 8 inches of yellow pine were used, as shown in Fig. 78.

Mooring Devices

Devices for attaching the mooring lines of vessels to a wharf may be in the form of piles, posts, cleats, or rings. Mooring posts, belay posts, snubbing posts, bitts and bollards are local names for the same general class of mooring fixture.

These fixtures should be designed for use with hemp or wire ropes, arranged so that the lines may be readily attached and detached, and made of materials which will not be easily worn out by use and which will not cause undue wear on the ropes. The diameter should be large so as not to cause sharp bends in the lines. Mooring devices should also be so shaped that the hawsers of a large vessel the decks of which may at times be far above the deck of the wharf will not slip off. They should be capable of easy replacement and renewal when worn out or broken.

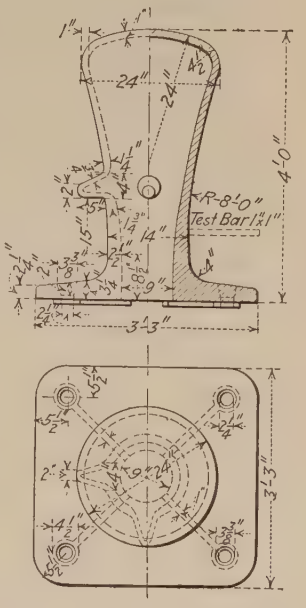

Fig. 124. C. I. Mooring Post, for Corners of Piers, New York Dock Dept.

Timber piles, driven through a properly braced opening in the deck of a wharf structure, or into a solid fill, are easily worn out, are subject to decay, and are usually not sufficiently cheaper than other kinds to justify their use for permanent structures.

Granite has been tried in some cases, but mooring posts of this material, while they have a handsome appearance, are expensive, brittle, and difficult to replace when broken.

Reinforced concrete has also been used. It is, unless protected by metal, rapidly worn out by wire ropes and it wears out the rope.

Cast iron and cast steel are the most suitable and most generally used materials for this purpose.

The large post shown in Fig. 124 has been in use for

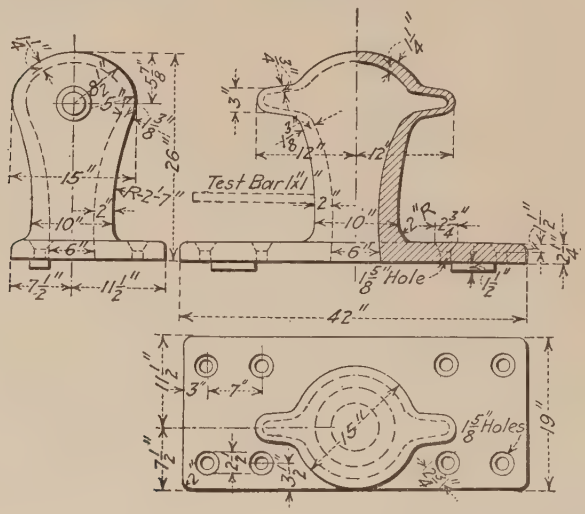

Fig. 125. C. I. Small Bitt, New York Dock Department.

the outer corners of piers for many years in New York. The horns were added to prevent the slipping off of the hawsers of very large vessels. Mooring posts of such great height are unnecessary except at the corners of piers, where it may be necessary to fasten a number of lines at the same time. Posts for the corners of piers should be stronger than those on the sides, as extra heavy stresses are put on them in docking vessels. The small bitts, Fig. 125, are used for the sides of piers and are suitable for all but the very largest steamships. Cleats of the pattern shown in Fig. 126 are used for lighters, tugs, etc. They are also used as fair-leaders in connection with corner mooring posts, as shown in Fig. 127.

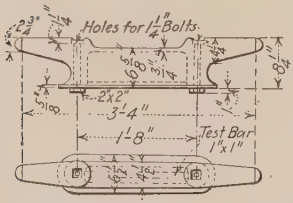

Fig. 126. C. I. Mooring Cleat, New York Dock Dept.

A mooring or "belay" post of steel plate filled with reinforced concrete was used on the B. & M. R. R. piers in

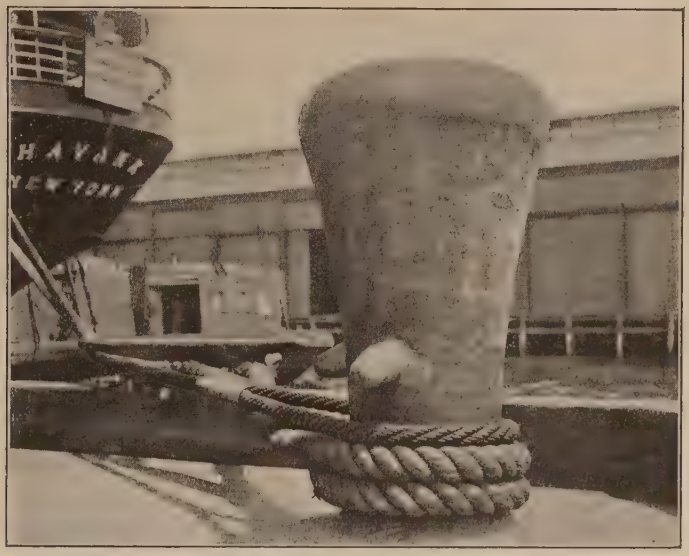

Fig. 127. Corner Mooring Post with Cleat used as a Fair-leader.

Boston. Fig. 76 illustrates a form of "bollard" common in European practice. An unusual form of double bitts was designed for the piers recently built in San Francisco and is shown in Fig. 123.

An excellent form of mooring post is that used on the concrete wall at Oakland, Cal., shown in Fig. 128.

Other forms are shown in Figs. 13, 18, 51, and 77.

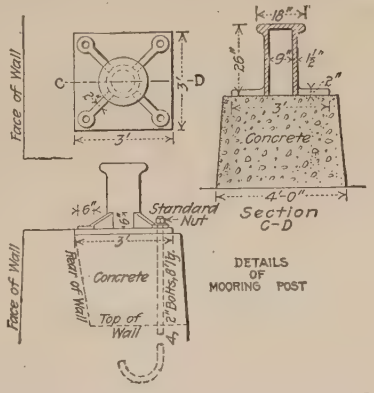

Fig. 128. Mooring Post, Oakland, Cal.

The usefulness of double posts or double bitts on a wharf is not apparent where the mooring devices are used

simply to hold a line in the end of which a loop is spliced or tied. Appliances of this form are more useful on the vessels where the lines are handled, adjusted for length, and made fast.

Mooring rings are sometimes placed in the faces of

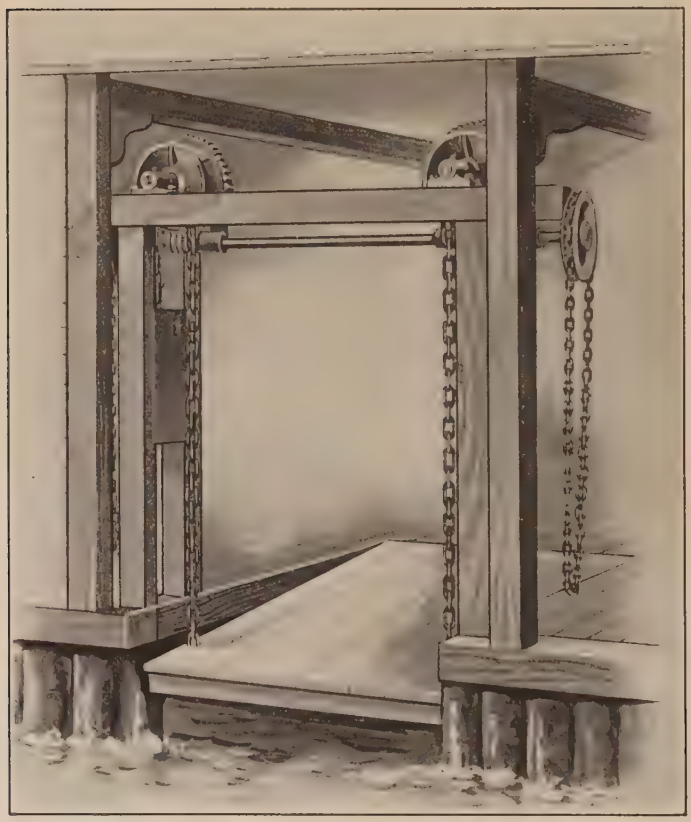

Fig. 129. Wharf Drop.

masonry walls or on the top. They are not to be recommended, as they are clumsy, inconvenient, and cause sharp bends in the hawsers and consequent injury.

Wharf Drops

Wherever it is necessary to transfer freight between wharf and vessel by means of trucks in localities where

there is a considerable rise and fall of the water surface, "wharf drops" or movable gangways are required. These are sections of the deck hinged at one end and suspended from overhead frames at the edge of the wharf so that they may be raised or lowered by hand-power gearing or by electric motors, as shown in Fig. 129. It is evident that if more than one of these gangways is to be used on a vessel at the same time they must be located to match the side ports of the vessel. These gangways may be fitted with electrically driven chains equipped with projections to engage the axles of freight trucks and assist them up the grade, as described in Chapter VIII.

Pavements

Pavements for wharves should offer a good foothold for men and horses. They should be smooth where trucks for moving freight are used. They should be non-absorbent, so that water and other liquids cannot soak into them. The wear on wharves where there are many horse-drawn trucks is frequently concentrated in narrow lines, and on many wharves the traffic is so dense that pavements wear very rapidly. Such pavements should therefore be easily removed and repaired when worn out. Those for pile wharves should be light in weight.

The substances used for pavements and wharves are plank, concrete, sheet asphalt, wood block, brick, asphalt block, and granite block.

Plank is the least durable material, but it is absorbent, and where there are very many horse-drawn trucks it acquires an offensive odor. It is, however, light, elastic, and low in price. Pacific Coast white cedar is said to be superior to other woods for this purpose. Vertical grain fir is also used on the Pacific Coast. In New York 3-inch yellow pine sheathing requires complete renewal after six years. In San Francisco Douglas fir is said to have lasted only one year and white cedar two years.

Concrete is low in first cost, but it is very difficult to

make it durable where there is much horse trucking. The grinding action of heavy loads on narrow-tired wheels, due to the frequent turning necessary in manœuvring wagons in the narrow roadways, is particularly destructive to it.

A light sheet asphalt pavement on a concrete base has been found very satisfactory. It is cheap, elastic, and can be easily repaired. In New York a pavement $2\frac{1}{4}$ inches thick costs only from 10 to 15 cents a square foot with a five-year maintenance guarantee. An objection to such pavements, however, is that they are liable to be indented in warm weather by sharp objects, such as the ends of casks and barrels. Sheet asphalt pavements the surface of which is composed of broken stone and sand are less subject to this defect than those made with sand only.

Pavements of creosoted wood blocks have been used with great success on many piers. They are light and can be laid directly on either plank or concrete foundations, but the first cost is very high, and where there is little traffic the blocks are said to shrink and become loose. In Philadelphia the price is about double that of asphalt.

Brick, asphalt blocks, and granite blocks are, on account of their weight, more suitable for solid-filled wharves than those on pile foundations. They are somewhat difficult to repair satisfactorily when unevenly worn.

Railroad Tracks

Where it is necessary to have railroad tracks on a pier they may be placed in the middle or at the edge and may be placed at the elevation of the surface or depressed so that the floors of the cars are on a level with the deck. They should be arranged so as to waste as little wharf space as possible and to produce a minimum cost in handling the freight.

Depressed tracks have the great disadvantage that they form a barrier against the movement of trucks. They may be crossed on movable bridges, but the latter interfere with the shifting of cars. Where motor trucks are used

for handling freight, portable platforms and ramps may be used to enable trucks to enter box cars, instead of depressing the tracks, and where overhead cranes or telephers serve the cars, portable platforms will provide all the advantages of depressed tracks. The space occupied by depressed tracks cannot be used for any other purpose, while if the tracks are at the level of the top of the wharf the space occupied by them when not filled with cars can be used for trucks or storage.

A double track in the middle of a pier wastes less deck room than a track on each side and has the advantage of permitting the installation of cross-overs between the tracks which facilitate the shifting of the cars. A single track on each side of the pier can seldom be kept full of cars, and, even if not depressed, the space it occupies on a shedded wharf cannot be used for other purposes when not occupied by cars.

If the tracks are placed on the sides of a pier there is some saving in the width of the shed required.

It is seldom practicable to transfer general cargo, with the appliances in use at present, directly from car to ship or from ship to car. In the first case a double track on the side of the wharf is required with frequent cross-overs if more than one hatch is to be loaded at the same time and the loading is not to be interrupted by the shifting of the empty cars. It does not pay to run a travelling crane longitudinally on a wharf for transporting freight from the end of a string of cars to the vessel's hatch, as so much time is lost in travelling that it is usually cheaper to keep the crane stationary and transport the goods from the car to the machine by hand or motor trucks. In unloading a vessel the freight nearly always has to be sorted before it can be put in the cars.

Direct transfer between car and vessel is much more common in Europe than it is in this country. This is probably due to the nature of the rolling stock. The cars used abroad are very much smaller than ours and open cars

or what are termed "gondolas" in this country are used for everything but very small and valuable packages, the freight being protected from the weather by tarpaulins. Our box cars are not adapted for rapid loading and unloading with cranes or telephers, but it is possible that as the demand for the use of such machines increases, box cars will be made with removable roofs so that they may be loaded and unloaded without the use of platforms or hand trucks.

In New York there is considerable direct transfer of freight between cars and lighters. It is to a great extent limited, however, to machinery and similar goods carried on flat or gondola cars. Special piers are provided for this purpose, equipped with several lines of tracks and with locomotive revolving cranes or gantry cranes of the pattern shown in Fig. 140.

Fire Protection

The fire risk on freight piers is considerable, both external and internal. Fires on wooden wharves have frequently resulted in the total destruction of the structures themselves, the freight, and the vessels lying alongside. There have been cases, however, where the sheds and freight have been destroyed and the wooden pier decks were not even burned through. The principal risk is from the cargo, which is often of much greater value than the pier and shed, so that it is of more importance to safeguard the cargo from fire than the wharf structures. Among the most usual known causes are defective electric wiring, spontaneous combustion of baled cotton, fires on vessels alongside, and burning oil floating on the surface of the water.

Many wharves have been constructed, not only without any regard whatever to fire protection but in such a way as to increase the risk in many unnecessary ways, and it is only within the last few years that much attention has been given to this subject.

The general requirements for protection against fire are, for piers and sheds, as follows:

1. The division of the space in the sheds and under the deck of the pier by fire walls, with self-closing fire-proof doors in all openings, in order to confine a fire to a comparatively small space and to permit of its being extinguished by the firemen. This is the most important of all the requirements.

2. The use of automatic sprinklers properly maintained and inspected, also of water curtains along the outside of pier sheds.

3. The use of materials which are not destroyed by fire, such as reinforced concrete and steel encased in concrete or tile; or which resist fire, such as heavy timber and the elimination of destructible materials such as unprotected steel frames, wooden beams, joists, and purlins of small section, and wooden siding.

4. The use of automatic alarms.

5. The installation of fire buckets, chemical extinguishers, and hose.

6. The elimination of openings as far as possible in the upper floors of sheds which are more than one story high. The enclosure of all elevator shafts, stairways, and other openings with fire-proof walls, equipped with self-closing fire-proof doors.

Fire Walls. — The huge undivided space in large pier sheds has often acted as a furnace when filled with freight. If the fire starts with the doors open at both ends it spreads with incredible rapidity — so fast that men at work on the piers have no time to escape except by jumping overboard. The heated gases sweep through the shed and set every combustible thing on fire. If the fire once gets under way, buckets, extinguishers, and hose cannot be used. The shed if not built of fire-resisting materials usually collapses in a few minutes, the roofing makes the efforts of the firemen of little use, and the fire usually burns itself out.

To make fire walls effective the openings in them should be as few and as small as possible and should be fitted with self-closing fire-proof doors. Such walls in the sheds are

inconvenient, as they interfere with the handling of the freight and are strenuously objected to by most pier superintendents, but these objections are being overcome and the use of walls is rapidly increasing.

The use of thin wooden deck joists and of pile caps and rangers or stringers in pairs, separated by a narrow space, are particularly objectionable as far as the fire risk is concerned. Such caps and rangers afford the best possible conditions for maintaining a fire under the deck of a pier and are most difficult to reach with fire hose. To offset this objection the New York Dock Department places reinforced concrete fire walls about 300 feet apart in their wooden piers, extending from the deck to low water and from side to side of the pier, with hatches in the deck at intervals of about 50 feet to provide access for firemen to the space underneath. Such walls help to confine a fire under the deck of a pier to a small area.

Sprinklers. — The automatic sprinkler is the best and most economical method of prevention and control of fires on piers and wharves and costs only about 10¢ a square foot of floor space. The installation and maintenance in efficient condition of this device in a pier shed is of more importance than the construction of the shed of materials indestructible by fire, as the sprinklers protect the freight as well as the shed, even if the latter is built of materials which do not resist fire. It is the freight which usually furnishes the greater part of the fuel, and often causes a greater money loss than the shed. Even if the shed is of the best fire-resisting construction the sprinklers should in no case be omitted if freight is to be stored in it at any time.

It is only of late years that sprinklers have been used on piers and their use is spreading but slowly. This is due in some instances to lack of capital and perhaps some explanation may be found in the way in which the interest in fire protection is divided among the parties which own and use the pier. For example, one company may own a pier and rent it to a steamship company which carries freight

owned by individual shippers. The latter pay for the insurance on the cargo, which is carried by the steamship company and is included in the freight rates, and they supply the greater part of the fuel in case of fire. The steamship company which leases the pier maintains and inspects the sprinkler system, which is owned by the party who owns the pier. The owner is interested in the possible loss of income if the pier is burned, but as it is difficult for him to make sure of the proper care and inspection of the apparatus, without which it is worthless, he hesitates to spend money on the installation. The interest of the steamship company lies in the decrease of the risk of destruction of freight and vessels lying alongside the pier, and in the decrease of rent which includes the insurance on the pier, and in a possible decrease in the insurance of the freight.

The shipper is only slightly interested, as the difference in freight rates due to the sprinklers on a pier may be comparatively unimportant.

It is difficult to understand why the owners and lessees of piers do not see the advantage of sprinklers, which is shared by both, in a stronger light and why any difficulties in maintenance of the apparatus cannot be obviated by clauses in the leases requiring proper maintenance and inspection by the companies which make a specialty of such work and are thoroughly reliable.

The best practice requires that a sprinkler system should be supplied with water from at least two different sources, one of which should be an elevated tank properly protected against frost. The other supply should be from the city mains, if available, or from fire pumps. Connections should be supplied at both ends of the pier for fire engines and fire boats. The dry-pipe system of water distribution is necessary on piers where water in the pipes is subject to freezing. Cornice sprinklers or "water curtains" should be installed on the outside of the sheds for protection against exterior fires, such as burning ships. Perforated pipes

with connections for fire boats and fire engines have in some cases been placed under the decks of wooden piers.

Roof Hydrants. — Roof hydrants are useful for fighting fires on ships and lighters lying alongside a shedded pier.

Fire-resisting Materials. — The use of fire-resisting materials, such as reinforced concrete or steel encased in hollow tile or concrete, makes a pier shed so heavy that it increases the cost of a pile foundation very considerably and for this reason structures having fire-proofed walls, frames, and roofs are unusual on pile piers. Their number, however, has increased considerably in recent years.

Unprotected steel roof trusses or second-story floor beams, though incombustible, will collapse in a very short time if subjected to a fire in the freight under them, as has happened in many instances. Such collapses have often resulted in the fire burning itself out as stated above.

Heavy wooden columns and trusses will stand up much longer in a fire than unprotected steel, but are usually so reduced in section after a fire that they have to be replaced. They are useful in that they are slow burning and permit of effective work by firemen in saving the cargo.

The sides of a shed should always be of incombustible material and all glass in windows and skylights should be wired.

Piers which are constructed of wood between the water and the deck are subject to fire risk from vessels alongside and from floating burning materials. They may be protected from this risk by sheathing on the outside, provided that sufficient ventilation is provided under the deck to prevent rot, as has been described in previous chapters.

Automatic Fire Alarms. — Automatic fire alarms which operate from local application of heat should be used in sheds to give notice of incipient fires in the freight.

Miscellaneous Equipment. — Piers should be equipped with fire buckets and in cold climates with tanks of water to which enough salt has been added to prevent freezing. Such tanks, containing both salt water and a number of

buckets, are sold by the dealers in fire-extinguishing supplies and are most suitable for the conditions existing on piers. Hydrants and hose should also be installed and should be arranged so that they will not be obstructed by freight piled in front of them.

Watchmen's clocks should be included in the fire protective apparatus in order to ensure the efficient patrol by the men employed for the purpose.

CHAPTER VIII

CARGO–HANDLING MACHINERY

General Considerations

This chapter treats of machinery for handling package freight and does not cover apparatus for bulk cargoes, such as coal, ore, grain, and oil, for which special machinery is required for each kind of material.

Object. — The object to be attained by the installation of freight-handling machinery on wharves is the reduction of the cost of transportation by saving in the cost of labor, by increasing the speed of loading and unloading vessels, and by reducing the cost of high tiering of freight on the wharf. The increase of speed increases the efficiency of the vessels by increasing the tonnage carried by ships in a given time, and economical high tiering reduces the area of wharf necessary to handle the required amount of freight.

Function. — The function of cargo-handling machinery for wharves is the transfer of freight between the wharf and the vessel and its transportation on the wharf. The commonest method is by use of the ship's hoisting gear and two-wheeled or four-wheeled longshoreman's hand-trucks. This method may be made very rapid, but it is very expensive, the principal factors being the large amount of highly paid labor and the large area of wharf required. Up to within a few years ago little progress had been made in reducing the cost of cargo handling by the introduction of improved machinery and appliances. Some explanation of this may be found, as in the case of fire protection, in the number of parties involved in the various operations. For example, one company may own the wharf and shed and lease them to a steamship company which makes a

contract with a stevedore, at so much a ton for unloading the freight, which he deposits on the pier for the consignee's truckman to take away. It is difficult under such conditions to obtain coöperation among those interested and to introduce new methods and machinery involving large outlays of capital, the abolition of long-established customs and emoluments, and the overcoming of the objections to the introduction of labor-saving devices. In a very few instances, however, all the operations involved in the transfer of freight between vessel and consignee are controlled by one party, and where such conditions occur, may be found progressive policies and methods, and the successful use of machinery with reduction in cost and increase of efficiency of vessels and wharves.

Another reason why improved machinery has been introduced to such a small extent may be found in the fact that the advantage of any machinery involving high fixed charges depends largely on the "load factor," or ratio of employed to idle time. Where freight handling is conducted night and day the opportunity for economies by its employment is much greater than where such an equipment is only in use say one fifth of the time, as is often the case.

Operations to be Performed. — The operations to be performed in cargo handling may be divided into three classes:

1. Hoisting and lowering on the steamer, lighter, or other vessel.
2. Transfer between the vessel and the wharf shed, warehouse, car, dray, or another vessel.
3. Transfer between the shed and the warehouse, car, or dray.

Incidental to the transfer are sorting, weighing, gauging and measuring, marking, customs examining, sampling, recoopering, and checking.

On outbound freight, in order to keep the idle time of the vessel at a minimum, the sorting is usually limited to

putting the freight for each port of delivery together and stowing it with reference to its weight, bulk, and perishability. When the vessel has only one port of call a large part of this sorting is eliminated.

The result of this kind of loading is that when the cargo is unloaded it comes out of the ship with the consignments all mixed together. The sorting is usually done on the wharf, in order to save the vessel's time, and, with the other incidental operations, forms the greatest obstacle to the economical use of machinery on the wharf. The average consignment may vary from half a ton to one or more car loads, and the cost of handling and the possibilities for saving by the use of machinery depend to a considerable extent on this average size. In the sorting of small consignments the two-wheeled hand truck has the greatest advantage and motor trucks, telphers, or other carriers of large capacity are inefficient.

It is obviously impossible to formulate any general plan in regard to cargo handling and the object of this chapter is to describe various conditions which, in various combinations, may have to be provided for, and the methods and machinery in use.

Classification of Vessels. — Vessels may be divided, for consideration in connection with cargo-handling machinery, into those in which the cargo is hoisted on and off and those in which the cargo is trucked on and off. Transoceanic freight ships usually load their cargo through comparatively small hatches in the deck. Many coastwise vessels which carry both passengers and freight have extensive deck houses, few deck hatches or none at all, and load partly or wholly through side-ports, by means of trucks. On side-port vessels having more than one cargo deck, the cargo is hoisted from the lower decks to the deck on which the trucks enter by means of elevators or cranes installed on the ship. Bay, sound, and river steamboats usually are in the second of the above classes. Canal boats are in the first class but do not carry hoisting gear. Derrick

lighters are in the first class and covered lighters in the second.

Heavy Packages. — Packages weighing over five tons cannot usually be handled by the ship's gear. Floating cranes and derricks are used in most ports for this purpose, as it is not economical to equip the wharves with machinery capable of handling occasional loads of such weight.

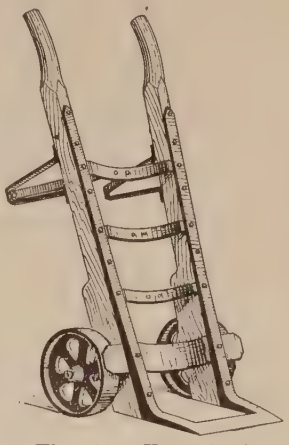

Fig. 130. Two-wheel Freight Truck.

Classification and Description of Machinery and Appliances

Machinery for freight handling may be classified into that used for hoisting and transporting. The appliances for hoisting are cargo booms, winches, hatch-cranes and elevators, on the vessels, and cranes of various patterns, telphers, cargo masts and portable winches on the wharves.

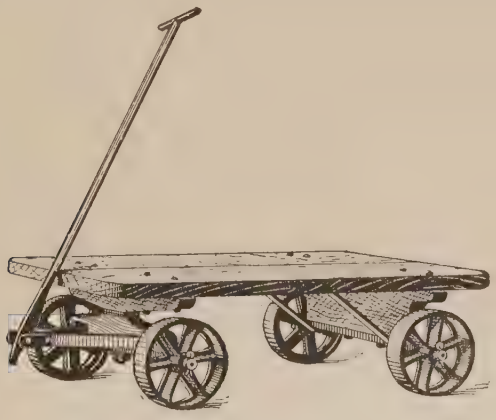

Fig. 131. Four-wheel Freight Truck.

For transferring freight between vessels and wharf shed there are, in addition to all the above, except the ships' cranes and elevators, two and four-wheeled hand trucks,

motor trucks, and portable conveyors, and for transporting freight on the wharf there are, in addition to these, flat-boards or low four-wheeled trucks drawn by horses or mules, motor trucks with trailers, and overhead travelling cranes.

Other appliances are portable electric controllers, inclined truck elevators, slides between wharf and vessel, and chutes and other devices for use between the floors of double deck sheds.

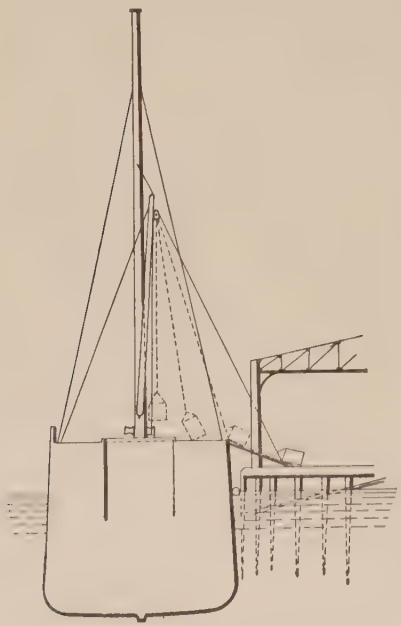

Fig. 132. Loading Ship with Inclined Skid.

Ships' Gear.—Freight ships for trans-oceanic trade are usually equipped with masts and from two to seven cargo booms and winches to each hatch.

Fig. 133 shows a recently built type of freight steamer with a very elaborate equipment of cargo gear which permits of handling cargo from each of the two largest hatches on both sides of the ship at the same time. One cargo boom on each mast is designed to handle extra heavy loads. Fig. 134 illustrates a steamer with the ordinary equipment of cargo booms. The winches are placed on raised platforms to permit the operators to see into the hold. This platform is only found on the newer ships. Fig. 135 shows a lumber schooner with very high booms and elevated platforms for the winches. The usual method of unloading with this equipment is to rig the booms of each pair at about 45° with the keel, hoist the load with both lines, and lower it with one. In loading the operation is reversed. With this arrangement the cargo can be

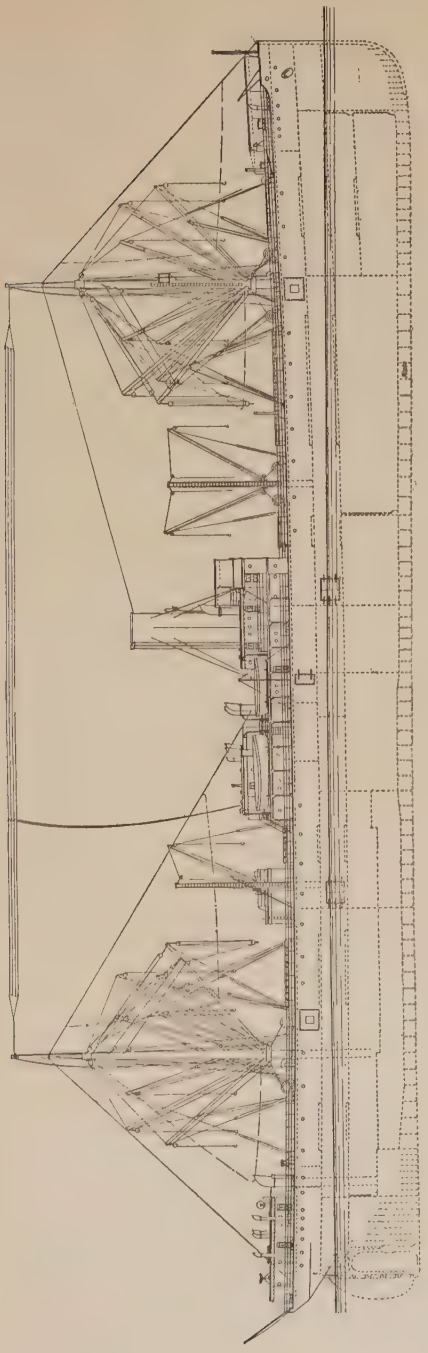

Fig. 133. Modern Freight Ship with Full Equipment of Cargo Booms.

handled on either side of the vessel without shifting the booms. The winches are arranged so that one man handles both lines and the extended operating platforms permit of a good view into the hold.

The type of winch in which the rope is not wound on a drum but on an extension winch head, thus requiring an operator for each line, is much in use and is apparently wasteful of labor. Double and triple drum, steam-driven winches, which wind the rope on the drums, are rapidly and safely operated by one man in handling derricks on land, and there is no obvious reason why similar machines should not be used on ships and wharves. Winches of this nature have recently been placed on the market and are shown in the illustrations.

Hatch cranes and elevators for vessels which load through side ports are shown in Fig. 138.

Wharf Machinery. — Wharf machinery is operated by steam, hydraulic, or electrical power, but the latter is almost universally used in new installations.

Cranes. — Of wharf cranes there are several patterns. The revolving crane is the most common. This consists of a derrick with a boom or jib which may be raised or lowered by an independent motor mounted on a turn-table which is carried by some sort of a car moving on tracks. The car may be of the ordinary low railroad type or may be of the "portal crane" or "gantry" type in the form of a movable bridge, spanning a roadway or one or more railroad tracks on the side of the wharf or pier. One of the rails may be placed on the side of a shed, in which case the machine is called a "semi portal crane." Such machines are usually built with little regard to the load on the track and are very heavy on account of the counterweights which are employed to balance the boom and the moving load. This is of considerable disadvantage on pile foundations, and some recent machines have been designed in which the weight has been reduced as much as possible. Revolving

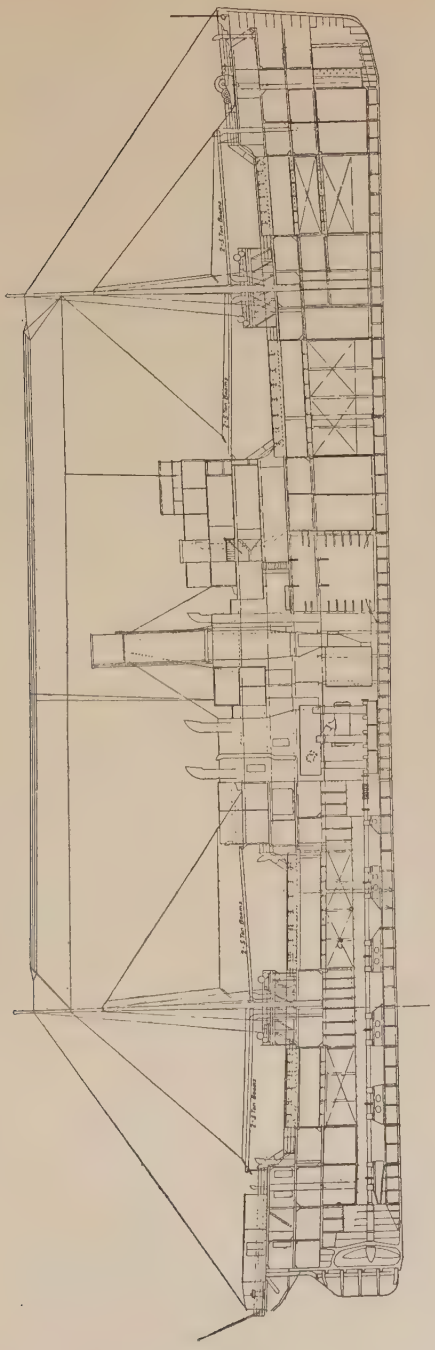

Fig. 134. Freight Ship with Ordinary Equipment of Cargo Booms.

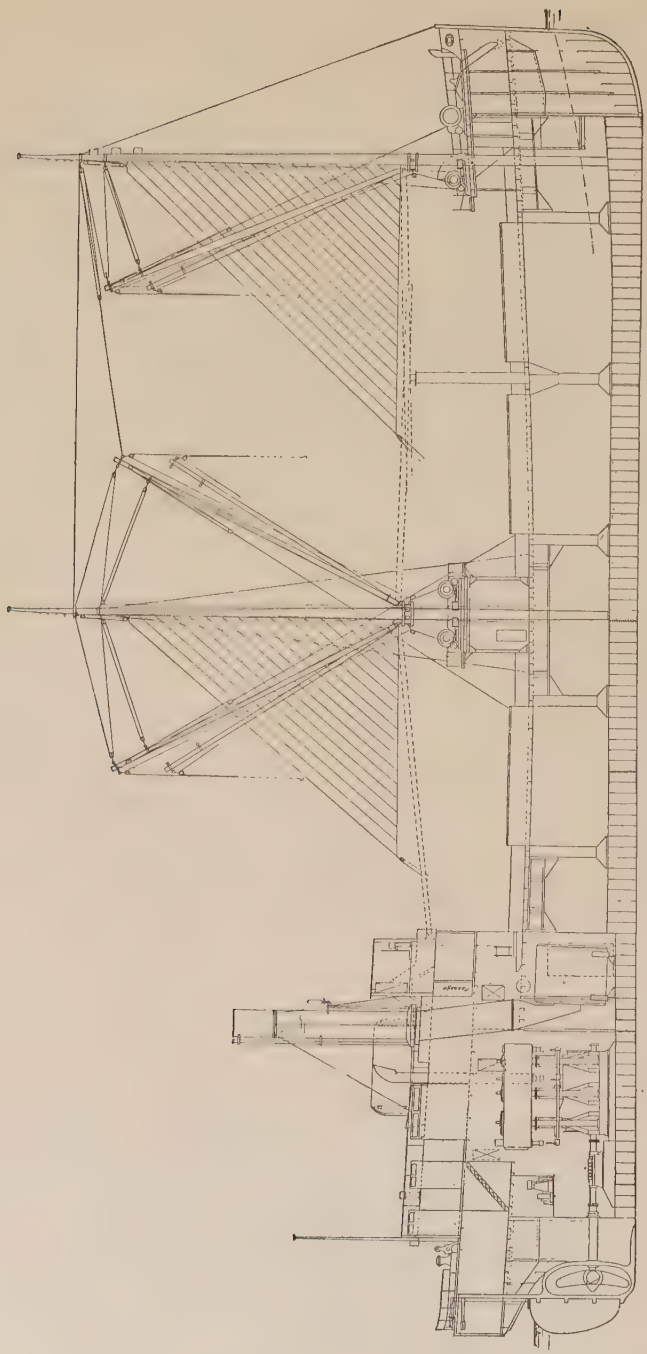

Fig. 135. Steam Lumber Vessel with Efficient Cargo-handling Gear.

cranes are also mounted on cars which run on the roofs of freight sheds.

Roof cranes may also be of the "straight line" type with

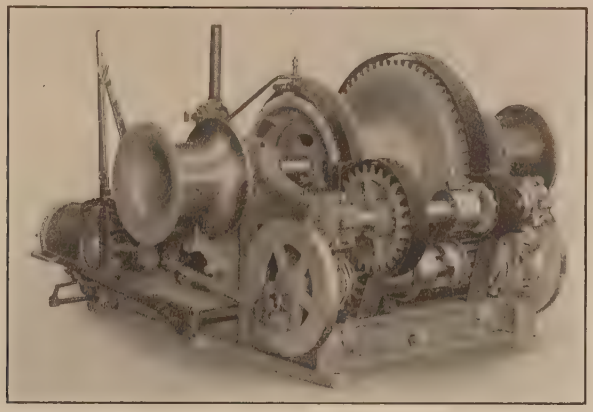

Fig. 136. Ordinary Type of Ship's Winch: Two Lines Operated by Two Men.

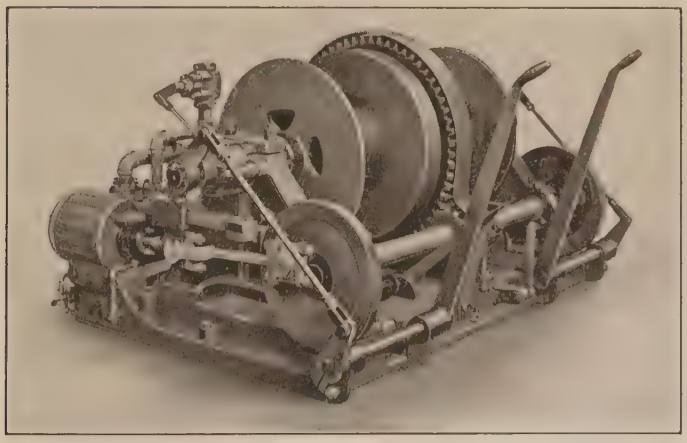

Fig. 137. Winch for Two Lines operated by One Man.

a vertically hinged arm carrying a trolley. Another pattern has the trolley arm suspended on trunnions in such a way that when it is in position for operating, it extends both over

the vessel and inside the door of a shed so that the loads can be landed inside the latter.

Telphers. — Telphers are electric cars running above the

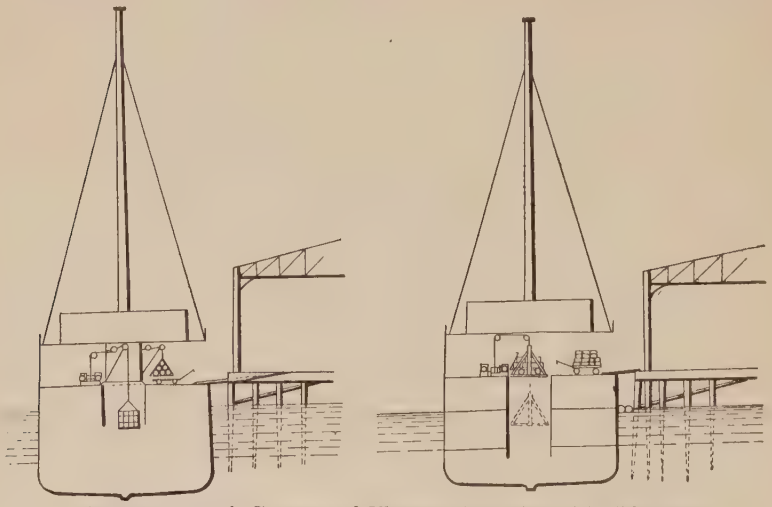

Fig. 138. Hatch Cranes and Elevator for Ships with Side Ports.

Fig. 139. Electric Locomotive Crane.

deck of a wharf at a height sufficient to clear the cargo, on single rails suspended from frames, either those of a freight shed or, in the case of an unshedded wharf, those

erected specially for the purpose. The car carries its motors, the operator, and electrically operated hoists for raising and lowering the loads. Each motor car may also be provided with a number of trailers similarly equipped with hoisting gear. The loads are carried in crates or on "flat boards" suspended from the motor car or trailers.

If the tracks are fitted with fixed switches they require many parallel lines of rails to cover a given area. A device called a gliding switch has been used considerably in Europe, and to a small extent in this country, which permits a rail on a travelling bridge or shop crane to be connected with another rail at right angles to it wherever the travelling crane may be, as shown in Fig. 145. This device allows such a travelling crane to be substituted for the numerous parallel cross rails necessary in the system using fixed switches. The combination of a travelling bridge crane fitted with rails and gliding switches permits the telpher to serve the entire area served by the travelling bridge.

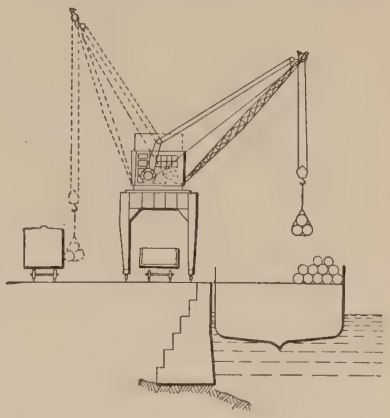

Fig. 140. Gantry or Portal Crane.

New York Cargo Hoists. — Cargo hoists, such as are shown in Figs. 96, 112, 116 and 118, have been developed in New York for transferring cargo between the wharf and steamships equipped with cargo booms and winches. For want of a better name they may be called the New York Cargo hoist. They consist of upright steel or wooden columns at the side of the pier shed which support wire cables or steel girders to which cargo-hoisting pulleys or blocks may be attached. The function performed by these hoists may be performed by an extra cargo boom on the ship, but they have the advantage of supplying a point of

suspension for the block at the best location, which cannot always be supplied by the ship's boom, especially when the

Fig. 141. Semi-portal Crane.

ship is moored at some distance from the wharf to allow coal lighters to lie between the ship and the wharf.

Fig. 142. Straight Line Crane on Roof of Wharf Shed, Rotterdam.

Portable electric winches are used on the wharves to operate whips or single hoisting lines rove through the blocks on the cables or girders between the cargo masts.

Motor Trucks. — Electric freight trucks operated by storage batteries have been placed on the market in recent years to take the place of hand-operated trucks. They have a capacity of about two tons and a speed of five to seven miles an hour. Some of them are arranged to run under a skid or platform with short legs, raise it a few inches, and

Fig. 143. Straight Line Crane delivering Freight inside Wharf Shed.

transport it with its load of freight. If these skids, which are inexpensive, are supplied in excess of the number of motor trucks, the efficiency of the motor truck is increased by reducing the time spent in loading and unloading it. Some motor trucks are fitted with cranes and some are designed to act as locomotives and haul a number of trailers.

Conveyors. — Portable, electrically operated conveyors, such as are illustrated in Fig. 150, are used for transferring freight in uniform packages, such as sugar, coffee, cement, canned goods, etc., from the vessel's hatch to the wharf.

They are made in sections which can be easily moved about. A slightly different form is used at the end of a line for tiering.

Portable Controllers. — Portable electric controllers have been used for some years in Europe and have recently been

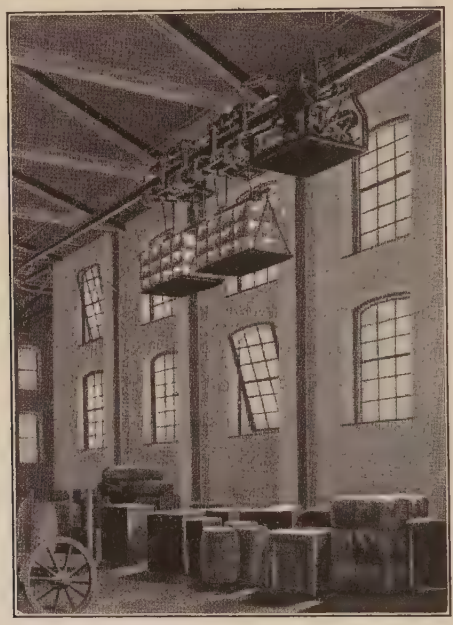

Fig. 144. Telpher Train.

put on the market by one of the large electric manufacturing companies in this country. They are carried on a belt worn by the operator and are connected to the motors of a hoisting winch or crane by flexible electric conductors. By use of this device the operator of a hoisting machine can stand at the edge of a ship's hatch and see the load he is hoisting at all stages of the operation, thus increasing the speed and dispensing with the services of signalmen. As they are made to control two motors, one man can operate a double-drum winch or two machines, such as a ship's winch and a dock winch.

Inclined Truck Elevators. — Inclined truck elevators consist of electrically driven chains running in a slot in a wharf-drop or inclined ramp. The chains are fitted with lugs or hooks which engage the axles of hand or motor trucks and carry them up the grades on which they require assistance.

Loading and Unloading Ships

Cranes vs. Ship's Gear. — The two principal appliances in use for hoisting freight to and from vessels not equipped with side ports are the ship's cargo gear and wharf cranes. In Europe the wharf crane is the most common and in this

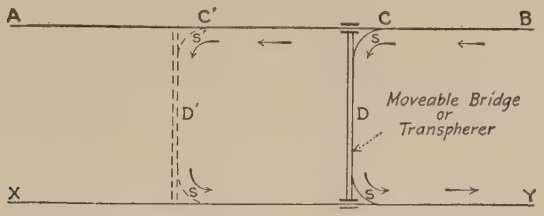

Fig. 145. Travelling Bridge with Gliding Switches.

country the ship's tackle is almost universal. When the ship's tackle is used one hoisting block is suspended from the end of a cargo boom over the hatch and another from another boom or from the cable or girder between the cargo masts on the wharf, over the point on the wharf where the load is to be deposited. Two lines are attached to the sling which carries the load, each leading to a drum of a hoisting winch. The load is first raised by one line, then transferred to and lowered by the other line.

Where wharf cranes are installed, they are usually used to hoist the freight from the hold of the vessel but sometimes the cargo is hoisted to the deck by the ship's winches and transferred to the wharf by the crane.

The comparative advantages of the two methods may be summed up as follows: The revolving crane wastes time in its rotary motion and the length of the path described by the load, also in stopping the hook or load at the proper

point. The crane is limited in its action by the shrouds on the ship's masts. The modern ship's gear is said to be as rapid on package freight as the revolving crane, even though the latter may lift a larger load. The crane requires

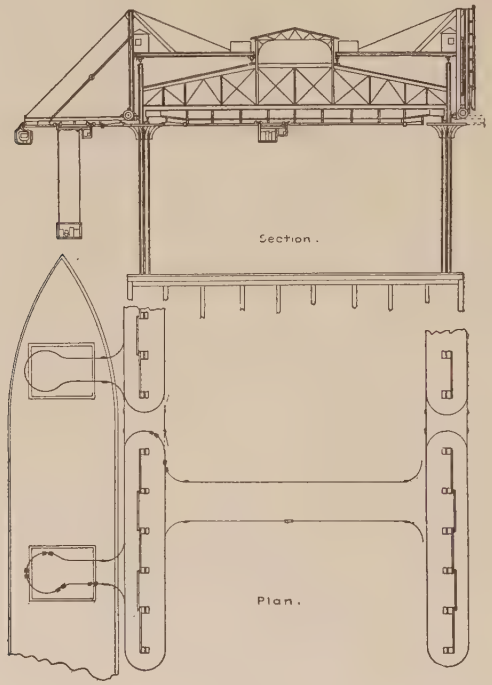

Fig. 146. Telpher System with Gliding Switches for a Freight Pier.

a larger outlay of capital than the New York cargo hoist and dock winch, and may be in use only a small portion of the time. It is often heavy and increases the cost of foundations in pile structures. It requires only one operator, while the two-line method usually requires two or more. This disadvantage may be overcome, however, by means of the portable electric controller described above. The crane is a necessity where cargo is to be transferred to and from barges and other vessels which have no cargo gear.

The modern crane and the modern portable electric dock winch combined with the New York cargo hoist are

both much superior in speed, and require fewer men to operate, than the ships' winches in ordinary use. For this reason they should, where there is sufficient traffic, be placed on wharves and piers except in cases where the ships using the wharves are equipped with an ample number of cargo booms and winches of the most economical type.

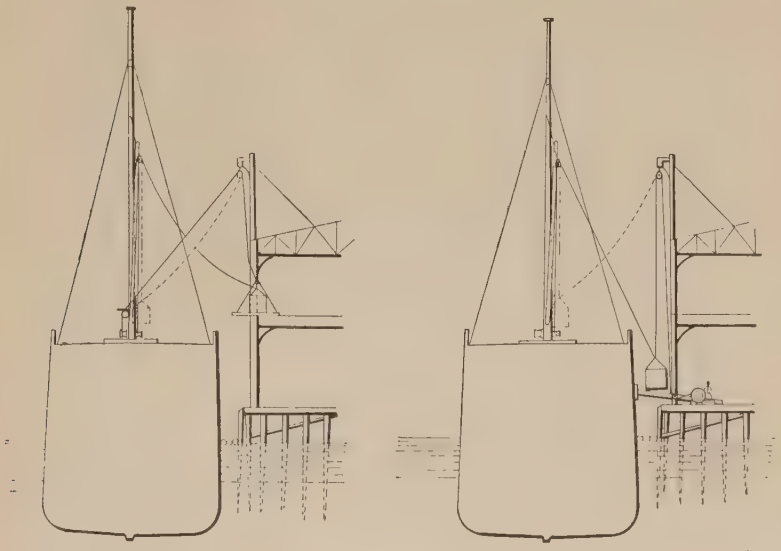

Fig. 147. New York Cargo Hoists, showing Use of Winches on the Ship and on the Pier.

The New York cargo hoist is more economical than the crane, is fully as rapid, and is therefore superior wherever it fulfils all the conditions. The crane serves a larger area than the ship's tackle and can, therefore, prevent congestion on the wharf due to delays in clearing the point where the freight is landed.

The straight-line crane does not serve so large an area as those of the revolving type, but its load does not have to follow as long a path.

In loading vessels the loads are often dragged up an inclined skid or slide between the wharf and the ship, thus

avoiding the use of two hoisting lines and the accompanying labor.

It is somewhat difficult to understand why the use of cranes is so prevalent abroad and so exceptional in this country, and why, when a steamship company with almost unlimited capital, a few years ago, rebuilt its piers which had been burned, it equipped them with the New York pattern of cargo hoists when the piers of the same company

Fig. 148. Electric Motor Truck.

in Germany are equipped with over one hundred revolving cranes. Many reasons have been suggested. One of them is that the crews are discharged and fires drawn in home ports in Europe, but retained here, and that boilers, winches, and crew are available here to work cargo. On the other hand, it is stated that one line of steamships handles cargo in its home port in Europe with the ship's gear, though the wharf is supplied with cranes; moreover, most ships are fitted with donkey boilers for operating winches, etc., when the main boilers are out of use. Besides this, the dock winch with the portable controller would be sufficient even if there were no power available in the ships. Another reason given is that the tidal range in some European ports is so great

that ship's tackle cannot be used to advantage when the tide is low. The New York cargo hoist would solve this problem

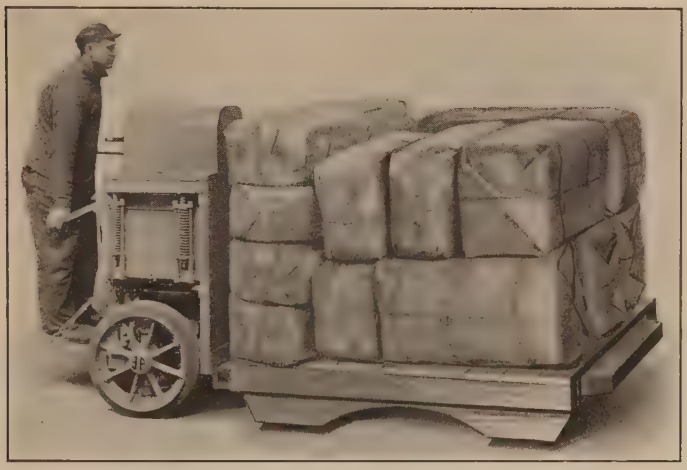

Fig. 149. Motor Truck with Separate Cargo Platform.

as well as the crane. Another possible explanation is that the cranes are supplied by the municipalities which own the docks, and that the steamship companies would not in

Fig. 150. Sectional Portable Conveyor.

many cases install them at their own expense. Probably the best reason is that at nearly all European ports there are a great many deep-hulled barges and similar vessels

which have no cargo gear at all and that many steamships are more or less deficient in their equipment of booms and winches, and that the revolving crane has a greater range of usefulness than any other form of cargo-handling ma-

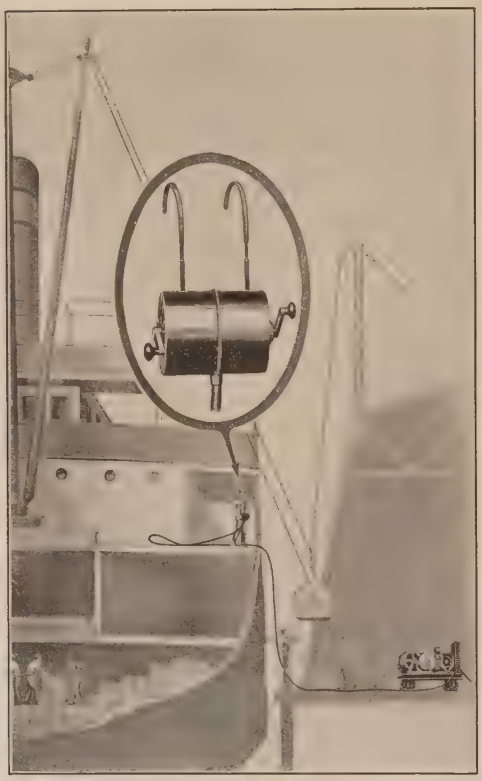

Fig. 151. Portable Electric Controller for operating Winches on Wharves or on Ships.

chinery. In New York, practically the only vessels which have no cargo gear which come to steamship piers are those which unload their freight by means of trucks from deck to wharf, and coal barges for coaling ships. The coal is hoisted by means of light temporary booms, ship or dock winches, or winches on small scows which accompany the coal barges. When the New York State Barge Canal is

completed it is expected that the vessels which will be used on it will be of over 2000 tons' capacity and that they will carry their cargoes in hulls about 12 feet deep and that they will have no cargo gear. It is probable that the wharves constructed by the State at the terminals on this canal will be equipped with cranes for cargo handling.

Neither the New York cargo hoist nor the crane will transfer freight between a steamer at a wharf and a barge or lighter lying on the opposite side of the vessel. The ships' tackle may perform this work if the hatch is large

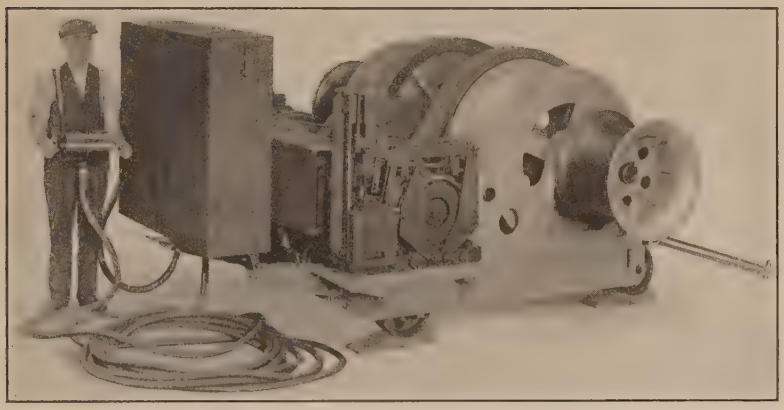

Fig. 152. Portable Electric Winch with Two Independent Drums and Portable Controller.

enough while a wharf crane is working on the opposite side of the steamer. If a steamer is equipped with only two cargo booms to a hatch the New York dock cargo hoist could not be used while freight is being transferred between ships and lighters unless a temporary boom were rigged up.

Speed-limiting Points. — The limiting point of speed in loading and unloading is usually on the vessel. The rate at which cargo can be handled is not limited ordinarily by the speed at which the hoisting apparatus can be operated but by the rapidity with which the cargo can be stowed in the hold or broken out and made up into loads for hoisting. With some kinds of cargo, when ships' gear and hand

trucks are used, the limiting point in unloading may be the landing point on the wharf, but such a condition is unusual.

Reservoirs. — As the operations in the vessel as well as those on the wharf are both subject to interruption and irregularities and in order that one may not delay the other and cause men and machinery to stand idle, a reservoir or place of deposit must be provided between the two

Fig. 153. Inclined Truck Elevator.

operations where the freight may accumulate and diminish. It is essential that there should be ample deck space at the point where freight is landed on the wharf by cranes or ships' gear to supply such a reservoir, and that, in order to avoid extra handling in the reservoir, an adequate supply of extra carriers should be provided except where the two-wheeled truck is the only means of conveyance. An example illustrating the above is found in unloading coffee in bags. The latter were hoisted by the ships' gear and deposited on four-wheeled platform trucks. Only enough trucks were provided to equal the capacity of the hoisting

apparatus. In spite of all efforts the trucks became grouped and there were times when it was necessary to stop the hoisting and with it the work of a large gang of men in the hold of the vessel, or deposit the bags on the deck of the wharf, to be subsequently loaded on to the trucks by additional labor. A reservoir consisting of an inclined slide with a capacity of two or three truck loads obviated the difficulty and made the hoisting apparatus the limiting element of speed. A similar condition may occur at the end of a line of conveyors.

Freight Handling on the Wharf

The cost of freight handling may be divided into that incurred on the vessel in stowing and breaking down cargo, the transfer between vessel and wharf, and the handling on the wharf. The average cost of unloading steamships has been estimated as follows:

Hoisting and lowering with cranes	\$0.02 to 0.05
" " " with two winches	\$0.04 to 0.10
Distributing and tiering	\$0.29 to 0.36
Loading on drays	\$0.20

Sorting before hoisting doubles the cost of hoisting and lowering. As there are almost no mechanical devices for reducing the cost of the work in the vessels' holds, and as the cost of transfer between vessel and wharf is only about one fifth of the cost of handling the freight on the wharf, the latter becomes the main point for attack in reducing the cost.

The principal appliances which today are available for this purpose, in place of the ordinary hand trucks, are storage-battery trucks and telphers. Other appliances to be considered are horse-drawn trucks, conveyors, and stackers.

Hand Trucks. — The two-wheeled longshoreman's truck transports a large load for one-man power, it is very flexible, allows of rapid sorting of small consignments, can be operated in narrow roadways, and has very low fixed charges for

interest repairs, depreciation, and insurance. It can be made rapid in operation, but it is high in labor cost. It can perform any of the functions of the other machines mentioned above except tier and load drays or railroad cars. It requires no expensive overhead structure or extra foundations, but it does require a smooth surface to operate on.

Electric Trucks. — The electric truck carries a larger load than a hand truck, moves faster, and requires less labor, but has a very high first cost, high charges for interest and insurance, a high maintenance cost, and should be charged with a high rate of obsolescence. It can go up grades without extra cost for labor, and, by means of portable ramps, it can enter box cars standing on the deck of the wharf. Equipped with a crane, it can load drays and cars, transport heavy packages, and tier to a limited extent. It will work at a speed which is uneconomical for hand trucks and thus increase the efficiency of ship and wharf. As it carries a larger load than the hand truck, it is not as flexible in sorting and distributing small consignments. When it is used in combination with a tiering machine, cargo can be tiered up to whatever height is required. Like the hand truck it does not require any special construction in the wharf shed.

Telphers. — The great advantage of a telpher system is that it serves every cubic foot of space in a shed, thus increasing the storage capacity by high tiering. It also decreases the amount of deck space required for passageways for trucks which operate on the deck. It can load and unload heavy packages from drays and cars. It can, by means of travelling loops extending over the decks of vessels, hoist directly in and out of the ships and can transport goods directly from a vessel to a warehouse on shore. It has a special advantage where it is possible to transfer freight directly between car and vessel. It does not require depressed tracks nor does it require frequent shifting of cars, as it costs little more, within reasonable limits, to transport a load a long distance horizontally at high speed than a

short one. In fact, it is a universal tool which can perform all the operations of freight handling on a wharf. It has the disadvantage, however, of requiring a building of special height, extra strength in the posts or columns, extra foundations, and, on wide piers, extra long spans in the roof, together with the necessary girders, tracks, switches and movable bridges, which entail large outlays of capital and increase of fixed charges. The rolling stock is somewhat cheaper than an equivalent number of motor trucks, as no storage batteries are required. The telpher system cannot be applied to sheds of ordinary height without sacrificing the high tiering which is one of its chief advantages.

In a design for a pier 1100 feet long and 150 feet wide, to be equipped with a telpher system, the estimated increase in the cost of the pier and shed due to extra height and weight of shed, a roof with three rows of posts instead of four, heavier foundations, etc., was about 5 or 6% and the cost of the equipment, which included overhead tracks, electrical equipment, 6 travelling bridges with gliding switches, 16 main track switches, and 4 trains, each consisting of one tractor and 3 carriers, was estimated at over $50,000.

Such a large initial outlay of capital is a great obstacle to the introduction of this system, especially where the amount of traffic cannot be definitely estimated. While this system is ideal from a mechanical standpoint, it has not had enough applications to prove whether it can be made more economical than hand or motor trucks.

Horse Trucks. — For long-distance transportation, such as that between a pier shed and a warehouse on shore averaging from 1000 to 1500 feet, the motor truck has to compete with trucks hauled by horses or mules. These are arranged so that the horse is easily shifted from one truck to another, so that the horse and driver do not stand idle during the unloading of the trucks. These are more economical than hand trucks for this purpose and are

governed by about the same conditions. Motor trucks for this purpose may carry the load or may be arranged as tractors to pull a separate truck. It is improbable that at present prices they can show superior economy to the horse as a tractor except for longer distances than those mentioned above, where their speed will have a large influence. A motor truck carrying a crate or flat board, which can be filled in the vessel, picked up by the motor truck from the deck of the pier and left at the warehouse to be unloaded while the truck is making another trip,

Fig. 154. Horse Truck for use between Piers and Warehouses, Brooklyn, N. Y.

would probably show the best results. Some such scheme could, however, also be applied to the horse-drawn truck, and it is doubtful if the superior speed of the motor truck for this service can compensate for the high fixed charges, except where they can be operated with a much higher load factor than is usual.

Direct Transfer between Cars and Ships. — A very considerable saving in the cost of handling freight could be made if it were possible to transfer direct between ships and railroad cars. The small percentage of freight which it is possible to handle in this manner is evidenced by the location and number of tracks on the piers in this country.

It is essential, if a large percentage of the freight on a given wharf is transferred directly between cars and ships, to have two or more tracks on the edge of the wharf. Such installations, with the exception of the case in New York mentioned in the previous chapter, are very rare in this country, but common abroad.

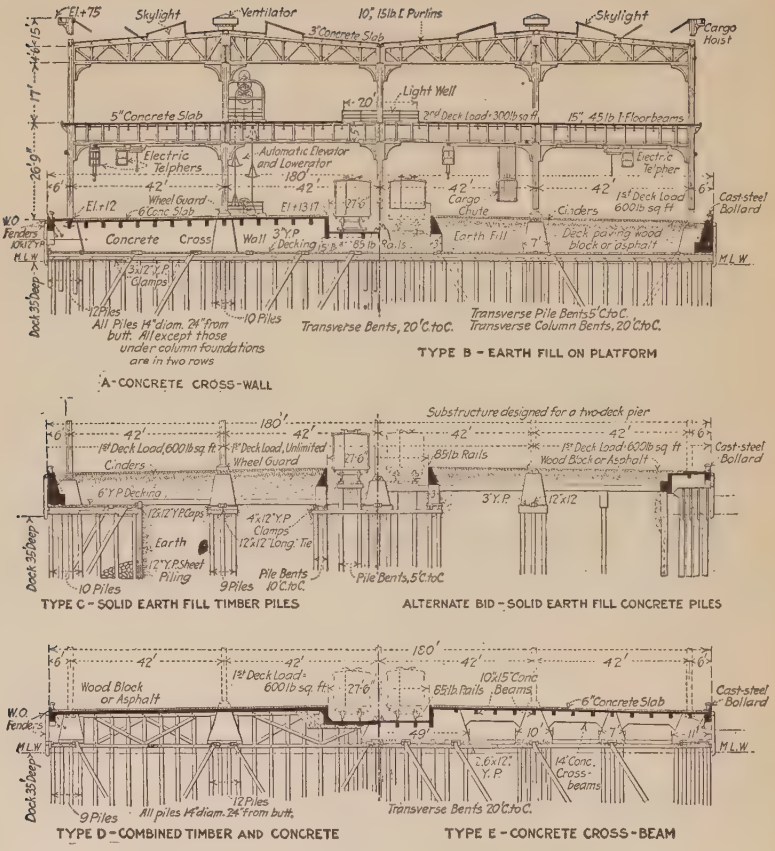

Fig. 155. Comparative Designs for Piers, Philadelphia, Pa.

APPENDIX

COST OF WALLS, PIERS, SHEDS, ETC.

Walls

The cost per linear foot of the following walls on the New York Barge Canal are based on the unit contract prices and on quantities estimated from the drawings. They do not include excavation or filling behind the wall. They are all designed for 12 feet of water except those at Buffalo and Oswego, which were in water 23 feet deep, and at Gowanus Bay, which provided for 17 feet at low tide. In the unit prices will be found the comparative costs of wooden piles, concrete piles, steel-sheet piles and concrete sheet piles which are useful in estimating the comparative costs of piers as well as walls:

N. Y. Barge Canal — Amsterdam: Timber Crib and Concrete. Similar to Fig. 12

Quantity	Measure	Item	Price	Amount
68.3	Lin. ft.	Round timber	$ .30	$20.49
3.14	Cu. yd.	Stone filling	1.75	5.50
2.44	Cu. yd.	Second-class concrete	7.90	19.28
.38	Lb.	Structural steel	.05	.02
1.0	Lin. ft.	Mall. C. I. nosing	1.00	1.00
4.46	Lb.	Iron castings — plain	.035	.16
		Total per lin. ft.		$46.45

N. Y. Barge Canal — Ft. Edward: Timber Crib and Concrete

Quantity	Measure	Item	Price	Amount
.136	M. ft. B. M.	Sawed lumber	$50.00	$6.80
59.7	Lin. ft.	Round timber	.20	11.94
5.1	Cu. yd.	Stone filling	1.60	8.16
.015	Pile	Mooring piles	8.00	.12
1.17	Cu. yd.	Second class concrete	6.90	8.07
1.00	Lin. ft.	Mall. C. I. nosing	1.00	1.00
.3	Fastening	Fender fastenings	1.00	.30
		Total per lin. ft.		$36.39

This wall was similar to that at Amsterdam, except that the crib was 3 feet higher and the concrete 5 feet lower. It included two longitudinal strips of wooden fenders.

N. Y. Barge Canal — Buffalo: Sawed Timber Crib and Concrete. Fig. 15

Quantity	Measure	Item	Price	Amount
.007	M. ft. B. M.	Sheeting and bracing	$40.00	$0.28
1.0	Cu. yd.	Lining	1.25	1.25
2.0	Cu. yd.	Ballast	1.50	3.00
.740	M. ft. B. M.	Sawed lumber	50.00	37.00
12.31	Cu. yd.	Stone filling	.40	4.92
.633	Cu. yd.	Block con., sec. class	9.00	5.70
.9	Cu. yd.	Second-class concrete	7.25	6.52
50.0	Lb.	Structural steel	.05	2.50
1.0	Lin. ft.	Mall. C. I. nosing	1.25	1.25
6.0	Lb.	Iron castings — plain	.04	.24
.4	Each	Fender fastenings	1.20	.48
		Total per lin. ft.		$63.14

N. Y. Barge Canal — Oswego: Sawed Timber Crib and Concrete
Fig. 16

Quantity	Measure	Item	Price	Amount
1.06	Cu. yd.	Ballast	$1.75	$1.86
1.100	M. ft. B. M.	Sawed lumber	47.00	51.70
11.68	Cu. yd.	Stone filling	.75	8.76
.6	Cu. yd.	Block concrete	9.00	5.40
.98	Cu. yd.	Second-class concrete	7.50	7.35
203.0	Lb.	Structural steel	.03¼	6.60
1.0	Lin. ft.	Mall. C. I. nosing	1.20	1.20
.5	Each	Fender fastenings	1.10	.55
5.0	Lb.	Iron castings — plain	.05	.25
		Total per lin. ft.		$83.67

N. Y. Barge Canal — Schenectady: Concrete Relieving Platform.
Fig. 39

Quantity	Measure	Item	Price	Amount
.024	M. ft. B. M.	Sawed lumber, fenders, etc.	$50.00	$1.20
44.8	Lin. ft.	Foundation piles	.25	11.20
.1	Pile	Fender piles	10.00	1.00
1.40	Cu. yd.	Second-class concrete	8.00	11.20
.20	Cu. yd.	First-class rein. concrete	15.00	3.00
5.35	Cu. yd.	Third-class riprap	3.00	16.05
5.8	Lb.	Structural steel	.05	.29
52.3	Lb.	Metal reinforcement	.035	1.83
4.7	Lb.	Iron castings — plain	.035	.16
1.0	Lin. ft.	Metal wall protection	.25	.25
		Total per lin. ft.		$46.18

This wall as built had timber piles substituted for the concrete piles shown in the illustration. There were some other variations.

N. Y. Barge Canal — Whitehall: Timber Relieving Platform. Fig. 40

Quantity	Measure	Item	Price	Amount
.222	M. Ft. B. M.	Sawed lumber	$55.00	$12.21
33.6	Lin. ft.	Foundation piles	.35	11.76
.1	Each	Fender piles	11.00	1.10
1.1	Cu. yd.	Second-class concrete	8.00	8.80
4.3	Cu. yd.	Second-class riprap	3.50	15.05
6.0	Lb.	Structural steel	.06	.36
4.59	Lb.	Iron castings	.04	.18
		Total per lin. ft.		$49.46

N. Y. Barge Canal — Rome: Steel-sheet Pile. Fig. 63

Quantity	Measure	Item	Price	Amount
.042	M. ft. B. M.	Sawed lumber	$60.00	$2.52
5.71	Lin. ft.	Anchor piles	.30	1.71
.143	Pile	Fender piles	13.50	1.93
22.3	Lin. ft.	Steel-sheet piling	1.20	26.76
.02	Cu. yd.	Second-class concrete	8.00	.16
.407	Cu. yd.	Reinforced concrete	15.00	6.10
77.0	Lb.	Structural steel	.05	3.85
24.0	Lb.	Metal reinforcement	.04	.96
2.0	Lb.	Wrought iron	.10	.20
8.0	Lb.	Iron castings — plain	.05	.40
1.0	Lin. ft.	Metal wall protection	.25	.25
		Total per lin. ft.		$44.84

N. Y. Barge Canal — Ithaca: Concrete Sheet Pile. Similar to Fig. 65

Quantity	Measure	Item	Price	Amount
.025	M. ft. B. M.	Sawed lumber	$50.00	$1.25
.11	Pile	Fender piles	11.00	1.21
.013	Pile	Mooring piles	8.00	.10
.57	Cu. yd.	Reinforced concrete	14.00	7.98
46.0	Lb.	Metal reinforcement	.04	1.84
6.0	Lb.	Structural steel	.06	.36
11.0	Lin. ft.	Rein. concrete sheet piles	1.40	15.40
.8	Lin. ft.	Rein. concrete square piles	1.25	1.00
1.28	Lin. ft.	Rein. concrete round piles	1.50	1.92
1.0	Lin. ft.	Metal wall protection	.25	.25
		Total per lin. ft.		$31.31

N. Y. Barge Canal — Albany: Concrete Sheet Pile. Fig. 65

Quantity	Measure	Item	Price	Amount
.086	M. ft. B. M.	Sawed lumber	$60.00	$5.16
1.12	Cu. yd.	Reinforced concrete	14.00	15.68
5.4	Lb.	Structural steel	.05	.27
184.2	Lb.	Metal reinforcement	.035	6.45
4.6	Lb.	Iron castings, plain	.04	.18
11.5	Lin. ft.	Rein. concrete sheet piles	1.45	16.68
5.06	Lin. ft.	Rein. concrete square piles	1.25	6.32
2.0	Lin. ft.	Rein. concrete round piles	1.75	3.50
1.0	Lin. ft.	Metal wall protection	.30	.30
.31	Fastening	Fender fastenings	1.00	.31
.4	Pile	Anchoring rein. con. piles to rock	7.20	2.88
		Total per lin. ft.		$57.73

The top of the Albany wall was 13 feet above mean water surface and that of the Ithaca wall only $3\frac{1}{2}$ feet.

N. Y. Barge Canal — Gowanus Bay, Brooklyn: Timber Relieving Platform. Fig. 31

Quantity	Measure	Item	Price	Amount
.192	M. ft. B. M.	Sawed lumber	$48.60	$9.33
66.54	Lin. ft.	* Foundation piles	.27	17.96
.092	Each	Fender piles	10.60	.98
1.27	Cu. yd.	Concrete	6.25	7.94
19.6	Cu. yd.	Riprap	.72	14.11
8.5	Lb.	Wt. iron and steel	.035	.30
2.5	Lb.	Cast iron	.03	.08
		Total per lin. ft.		$50.70

Bulkhead Wall — Department of Docks, New York

Type	Fig.	Cost per lin. ft.	Depth of water
Rock bottom	20	Min. $166.89 Max. 313.83 Av. 260.00	About 36 feet at low tide
Hard bottom	21	Min. 198.42 Max. 269.21 Av. 238.00	About 13 feet at low tide
Deep Mud, 1876	44	Min. 217.28 Max. 392.27 Av. 288.00	About 13 feet at low tide
Deep mud, 1899	47	Av. 278.50	About 13 feet at low tide

Includes dredging, but does not include filling and other incidental work.

Cost per Linear Foot of Principal Items

Item	Rock bottom type			Hard or firm bottom type			Relieving-platform type		
	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.
Dredging	$ 6.60	$107.00	$30.00	$11.00	$44.00	$32.00	$13.00	$62.00	$30.00
Riprap and cobble	4.50	12.50	10.40	12.50	19.50	16.00	24.00	84.00	44.00
Piling and timber work	.....	.....	.....	49.00	62.00	56.50	72.00	139.00	89.00
Concrete and granite	156.00	309.00	254.00	125.00	133.00	129.50	88.00	139.00	109.00

* Measured in place after cutting off. This price was considered very low. The engineer's estimate was 32¢.

The excavation for this wall cost $.185 per cu. yd., scow measure, and the pumped filling $.125 per cu. yd. bank measure.

ITEMIZED COST PER LINEAR FOOT OF A TYPICAL SECTION OF THE WALL OF 1876. FIG. 44

Dredging			$32.41
Riprap and cobble			60.61
Piling and timber work:			
Vertical piling		$47.40	
Bracing piles		6.88	
Binding frames		9.32	
Sawing off piles		4.76	
Longitudinal caps		5.12	
Transverse caps		8.37	
Decking		2.74	
Backing log in place		.74	
			$85.33
Masonry:			
Concrete blocks:			
Fabrication	$23.89		
Setting	9.35		
Filling chain-holes	1.64		
		$34.88	
Granite:			
Facing	$39.25		
Coping	10.91		
Pointing	1.34		
		$51.50	
Concrete backing		23.38	
			$109.76
Total for retaining wall proper			$288.11
General charges:			
Examination of the river bottom		$ .05	
Removal of old wall		18.27	
Filling in and grading		10.19	
Temporary paved approach to Pier No. 19		1.19	
Temporary tool house, fences and plumbing		.07	
Levels on an examination of the wall		.14	
Paving		62.20	
			$92.11
Total cost of improvement			$380.22

Average Unit Costs

Concrete blocks ready to ship per cu. yd.	$7.44
Setting concrete blocks per lin. foot of wall	38.00
Bag concrete foundation, deep rock type per lin. ft.	48.30

CONCRETE CAISSON WALL — WELLAND SHIP CANAL. FIG. 29

Caissons, 111 feet long cost, $11,000 each in place or..... $99.09 per lin. ft.
Concrete wall on top of caissons cost..... 4.50 per lin. ft.

Total cost of wall exclusive of filling of caissons and behind wall.....$103.59
If filling of caissons cost 25¢ per cu. yd., the total cost would be.....$112.00 per lin. ft.

It is stated that the contract prices for this work were very low and that 25% should be added in estimating the cost of similar work. This would make the cost for the wall, including filling of caissons, $140 per lin. ft. The depth of water is about 34 ft.

WALLABOUT BASIN, BROOKLYN, N. Y.

TIMBER RELIEVING PLATFORM WITH WOODEN SHEET PILING. FIG. 34

Cost per linear foot..... $80.00

STANDARD CRIB WALL, DEPARTMENT OF DOCKS, NEW YORK. FIG. 10

This wall costs about 8¢ a cubic foot when riprap is 50¢ a cubic yard. This would make the wall shown in Fig. 10, cost about $150 per linear foot for 40 feet of water at low tide.

CLEVELAND ORE DOCK — CONCRETE AND SHEET PILE. FIG. 54

This patented wall is said to have cost, per linear foot $28.40.

SAVANNAH, GA. — INCLINED CONCRETE PLATFORM. FIG. 41

Cost per linear foot..... $50.00

A similar wall designed for Baltimore with reinforced concrete piles was estimated to cost about the same as that at Savannah.

PIERS

Locality	Fig.	Type of construction	Cost per sq. ft.
New York, N.Y.	1	All wood	$1.00 for single pile row portion $2.50 for double pile row portion
San Francisco		Clusters of three timber piles in cylinder of plain or reinforced concrete; timber decks	$1.00
		Same as preceeding except caps are of steel I beams	$1.50
		Single piles encased in plain or reinforced concrete; timber decks; steel I beam stringers	$1.50 to $2.40
		All wood; creosoted piles	$.80 to $1.00
33d St. Brooklyn, N. Y.	70	1616′ × 150′ for one-story shed. Wooden piles; wooden caps; concrete deck slab; asphalt pavement; no side caps	$0.97
35th St. Brooklyn, N. Y.		1740′ × 175′ Wooden piles; wooden caps; concrete deck; slab wooden side caps	$1.08
29th St. Brooklyn, N. Y.		1199′ × 80′ Wooden piles; wooden caps; concrete deck slab; wooden side caps; asphalt pavement; no sewer	$1.21
30th St. Brooklyn, N. Y.		1134′ × 125′ Same as preceding	$1.19

PIERS — *Continued*

Locality	Fig.	Type of construction	Cost per sq. ft.
Philadelphia: Piers 38 and 40 tentative bids for comparison of costs. Riprap added and other corrections made to bring all on same basis for comparison	155	551′ × 180′ for two-story sheds. Type A. Wooden piles; concrete cross walls and deck Type B. Wooden pile platform supporting concrete walls and earth fill Type C. Solid fill Alternate. Concrete piles Type D. Wooden piles and caps; concrete deck slab Type E. Wooden piles; concrete posts, cross beams and deck	 $2.87 3.07 3.02 3.32 2.43 2.51
New York, Pier New No. 1		Concrete cross walls on rock bottom; concrete arches	14.00
New York, Pier A		Concrete cross walls on rock-bottom; steel girders, concrete arches	11.60
Bocas del Toro, Panama	77	Concrete — protected, wooden piles; concrete deck beams; concrete slab	2.13
Brunswick, Ga.	81	Concrete piles; wooden caps, bracing and deck	1.40
Charleston, S. C.		Concrete piles; wooden caps, bracing and deck	2.60
Oakland, Cal.	83	Concrete piles; concrete beams and deck	$3.25
Halifax Pier 2, I. C. R.	84	Concrete piles, beams and deck	2.89
Puget Sound Navy-yard, Washington, Pier 8		Concrete columns, steel deck-beams, concrete deck-slab	3.32
San Diego, Cal.		130′ × 800′ Concrete columns, single wooden pile under each column; steel beams cased in concrete; concrete deck	3.36
Olongapo, P. I.	88	Concrete columns; steel deck-beams; concrete deck-slab	2.60
Balboa, Canal Zone	90	Concrete columns, beams and deck	3.28

UNIT PRICES IN TENTATIVE BIDS FOR PHILADELPHIA PIERS 38 AND 40
1913–14

FIG. 75 (All prices are for materials in place in the work)

Types	"A", "B" and "C"		"D" and "E"		Alternate
Gravel or cobble filling, per ton	$ .65 to	$ .80	$ .50 to	$ .75	....
Riprap, per ton	1.50	2.25	.....	....	$1.25
Piles	16.00	20.00	14.00	20.00	21.00
Spur piles	18.00	33.55	15.00	25.00	23.80
12 in. sheet piling, per ver. lin. ft.	0.70	1.25	....	....	.80
Timber, clamps, caps, wales, decking	47.00	70.20	52.00	70.00	65.00
White oak fenders, per 1000 ft. b. m.	70.00	98.40	65.00	87.00	70.00
No. 1 reinforced concrete, per cu. yd.	11.00	20.00	11.00	15.00	11.00
No. 2 mass concrete, per cu. yd.	6.50	11.05	7.00	10.00	10.00
Reinforcement, per ton	45.00	100.00	40.00	100.00	70.00
Structural steel, per ton	50.00	100.00	55.00	100.00	80.00

PIER SHEDS

Locality	Fig.	Dimensions and Type	
31st St., Brooklyn, N. Y.		One story 1452′ × 141′ 8½	$0.75
33rd St., Brooklyn, N. Y.	111	Steel frame, gal. iron siding; gravel roof on plant; wooden doors 1593′ × 141′ 8½	0.98
New York Dock Co. Brooklyn, N. Y.	108	One story 461′ × 66′. Wooden frame, gal. iron siding; gravel roof	.95
Halifax,* Pier No. 2, I. C. R.	84	Two-story Reinforced concrete	2.07

* The interior fittings of the offices, waiting rooms, etc., which occupy 68,392 sq. ft., including heating, lighting, water piping for fire protection for the whole of the two stories, cost $105,716, or $1.54 per sq. ft. in addition to the above.

Cost of Steel Sheds per Cubic Foot

With steel at $60 per ton, erected, the cost of steel sheds as stated by Mr. S. W. Hoag, Jr., in 1905, was as follows:

Single story shed, exclusive of offices, etc. . . . . 3.8 ¢ per cu. ft.
Two-story shed, exclusive of offices, etc. . . . . 6.25¢ per cu. ft.
Office portion; one or two story sheds. . . . . .10¢ per cu. ft.

Miscellaneous

Concrete Columns. San Francisco — Piers 30 and 32, 1912, 3′ 10″ diam., $3.15 per lin. ft.; 3′ 6″, $4.93; 4′ 0″, $4.58.

Creosoting Yellow Pine Lumber. $8.00 to $10.00 more per thousand feet board measure for creosoted lumber in place than for untreated were bid in 1916 for the repair and extension of pier 6, East River, New York, N. Y.

"Gunite" Protected Piles. Covering piles with two inches of cement mortar, by means of the cement gun, cost 63¢ a linear foot of pile on the Pacific Coast.

Creosoted Piles. Fourteen pounds of creosote to the cubic foot of timber cost 27¢ on the Pacific Coast. Another authority gives 15 to 20¢ per linear foot with creosote at from 7.69¢ to 10.04¢ a gallon.

Granite. Granite for facing the bulkhead wall in New York cost, in 1912, about $1, cut and delivered ready to set. Setting cost about 40¢ exclusive of pointing.

Fire Protection. A dry-pipe sprinkler system for the freight sheds with wooden trusses and roofs and hollow tile walls, recently constructed for the Municipal Docks at Astoria, Ore., cost for

2,550 sprinkler heads	$12,000.00
Fire hydrants, standpipes, water main and a 50,000 gallon tank cost	8,500.00
	$20,500.00

A portion of the freight sheds was two stories high and the area served by the sprinklers was 130,170 square feet or about 51 square feet to each sprinkler.

The $12,000 covered valves, air-compressors, piping and all portions of the system, except the supply mains and tank and painting and frost-proof covering for the pipes, and figures out at $4.70 per sprinkler and $0.0922 per square foot of floor area.

The total cost of the fire protection per square foot including tank, hydrants, stand-pipes and mains, but not including painting and pipe covering was about $0.1575.

The tank and its supporting frame were of wood and cost $1,877.40.

Fire-proofing Steel Pier Shed Trusses with Mortar, Balboa, C. Z., Fig. 103. Eighty-four main trusses of 80-feet span spaced 17 feet apart together with the monitors and longitudinal trusses required about 12,000 square yards of expanded metal and 564 cubic yards of mortar. The cost of putting the expanded metal in place was about 8¢ per square yard and the mortar cost $18.33 per cubic yard in place with cement at $1.17 a barrel, sand at 86¢ cubic yard and common labor at 13¢ an hour. West Indian labor was used.

If 20¢ a square yard is allowed for the expanded metal, the cost figures out about $13,688.00 for about 116,000 square feet of area or something less than 12¢ a square foot.

Inclined Conveyor. Inclined conveyors on the Municipal Dock at Astoria, Ore., cost $3,000.00 each, including steel-trussed beams, all mechanical equipment, and power transmission.

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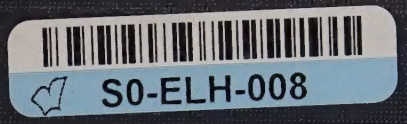
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